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LOAD SPECTRUM MEASURING EQUIPMENT. PART 1. DETAILS OF MK 1 SYST--ETC(U)
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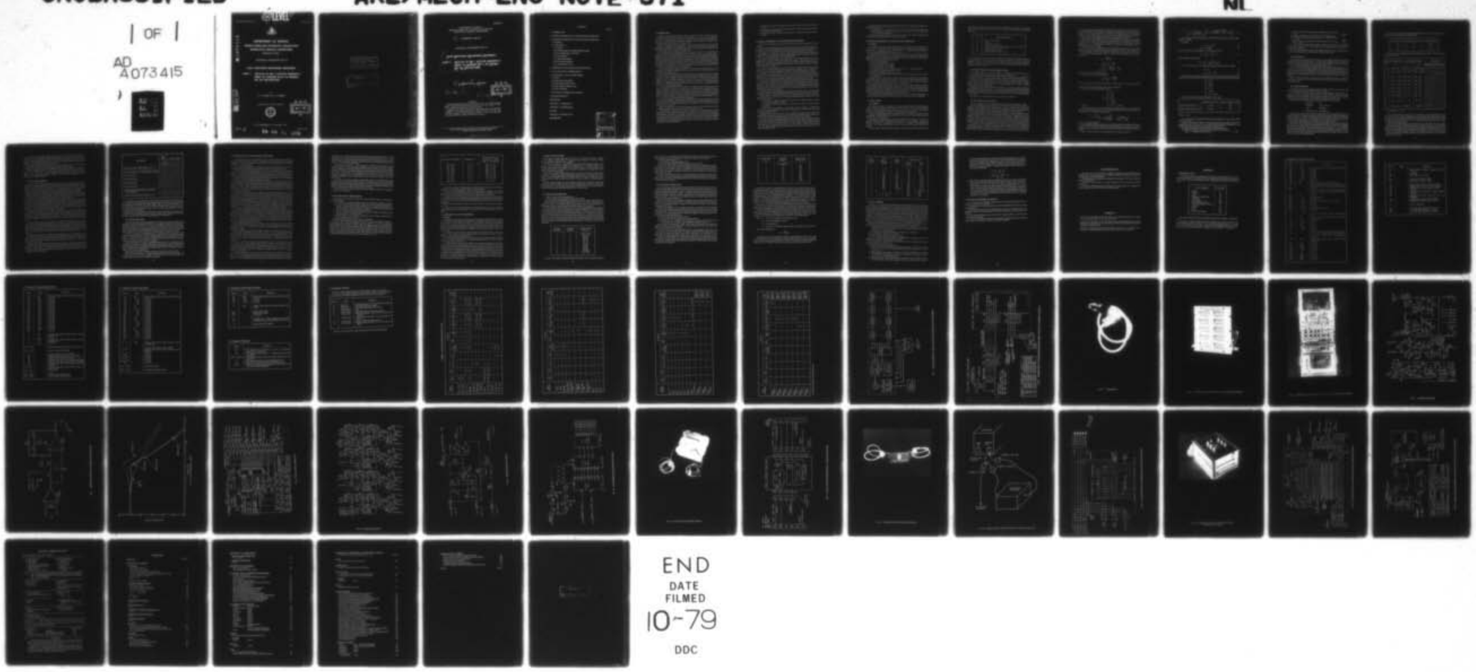

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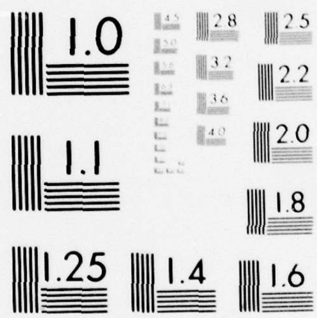

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MELBOURNE, VICTORIA

MECHANICAL ENGINEERING NOTE 371

LOAD SPECTRUM MEASURING EQUIPMENT

PART 1 DETAILS OF MK 1 SYSTEM PRESENTLY USED TO ACQUIRE DATA IN WESSEX MK 31B HELICOPTERS

by

K. F. FRASER and U. R. KRIESER

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SUMMARY

Measuring equipment has been developed which uses a set of electromechanical counters to indicate the integrated time in seconds for which torque loading on a transmission component falls within each of a number of bands.

Separation of the torque level into bands is made possible using a single transducer, an amplifier with zero and gain adjustments for setting the extremes of the torque range of interest, an analogue to digital converter and decoder to separate the torque range into bands and counters to totalize contributions in each band.

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1. INTRODUCTION

In order to make reliable predictions of the life of components subject to time varying loads, a knowledge of the load history is essential. Such predictions are of great value in relation to engine-driven components used in aircraft. Life estimates based on inaccurate or incomplete data may lead to components being overhauled or replaced more frequently than necessary with resultant increase in operating cost and "down" time.

Recently, equipment has been developed to allow long term measurement of the torque loading on a component in the main gearbox of Wessex Mk. 31B helicopters operated by the RAN (Royal Australian Navy). Loading is measured as the integrated time in seconds that the torque lies within each of a number of specified bands.

It is normal practice for helicopter pilots to be required to exercise care to maintain the developed torque within prescribed limits. Cockpit indication of the level of applied torque is therefore a necessity. To meet this requirement helicopter manufacturers frequently design special gearboxes which make torque indication convenient. The torque-measuring system employed in Wessex helicopters operates from a pressure being applied to vanes in the periphery of an annulus gear which forms part of an epicyclic gear train. The pressure is automatically adjusted to hold the annulus gear in equilibrium. In that case the pressure is proportional to the torque loading and in Wessex aircraft the pressure signal is transmitted directly to pressure gauges mounted in the cockpit. These gauges thus serve as torquemeters.

To sense torque for the torque level indicator it has been found convenient to insert a "T" connection in the hydraulic torquemeter pressure line and attach a pressure transducer. A strain gauge type of transducer is used.

One of the prime requirements of the torque duration totalizing equipment (called "Torque Analyser") is that it be capable of following any rapid changes in applied torque. It was therefore necessary to initially establish whether the Wessex system had an adequate speed of response. Validation tests[1] were therefore undertaken in which the torque level as measured from the output of a strain gauge transducer mounted directly on the output shaft of the engine reduction gearbox, was compared with that obtained from the pressure signal. It was established that the pressure system had adequate response.

It is to be emphasized that the Torque Analyser is a general purpose instrument with a wide range of applications. It need only be supplied with an analogue voltage signal proportional to torque, or whatever other quantity is to be totalized in the manner to be described. In general, unless the torque transmission system is specifically designed to allow indication of developed torque, the sensing of same may pose some problems. For example, the sensing equipment may have to be attached directly to a rotating member and the output coupled magnetically or otherwise to external (non-rotating) signal processing equipment.

Two sets of equipment, manufactured by WRE (Weapons Research Establishment) to ARL (Aeronautical Research Laboratories) design specifications, have been installed in Wessex aircraft, the first in July 1975 and the second in October 1975. Both units have operated satisfactorily since the time of installation.

Similar equipment[2] has been fitted in Sea King helicopters recently acquired by the RAN. Full details are given in Part 2 of this document under separate cover.

Instrumentation[3] which performs a similar function to that described herein has been produced in the UK by Westlands Helicopters Ltd. for fitment to some Wessex Mk.31B helicopters. The Westlands instrumentation was initially considered by the RAN for fitment to some aircraft but production delays were such that delivery could not be guaranteed to meet RAN deadlines. The Westland instrumentation requires a pressure switch for each torque band of interest. The instrumentation described herein which uses only one transducer to monitor pressure is considered to be preferable because:

(i) Installation of the pressure transducer in the aircraft is simpler than that for the pressure switches;

(ii) The transducer is expected to provide better long-term stability and require less frequent re-calibration than the switches;

(iii) Setting up the system with a transducer requires less adjustment than that with the switches.

2. GENERAL DESCRIPTION OF LOAD SPECTRUM INDICATOR

A block schema indicating the system used to provide torque spectrum indication is given in Figure 1.

A sensor providing an electrical output proportional to torque is, in the present application, provided by a pressure transducer inserted into the torquemeter pressure line in the port side lower engine bay of the Mk. 31B Wessex. Response down to zero frequency is provided.

The output of the transducer is taken to a DC amplifier with zero and gain adjustments provided. These two adjustments set lower and upper limits for the torque range of interest and are the only adjustments necessary at the time of calibration.

To remove any high frequency noise components, or any torque components out of the frequency band of interest, a filter is incorporated at the output of the amplifier. Conversion to digital form is performed on the filtered output using an ADC (analogue to digital converter). In effect the in-built analogue comparators contained in the ADC are used to divide the torque range of interest up into bands.

A clock, having good stability, initiates conversions at regular intervals in the ADC. Conversion rate is made sufficiently high to ensure that the input signal will not change much between successive conversion commands at the highest torque signal frequency of interest.

The digital output from the ADC is taken to a level decoder which effectively decodes the ADC output into a multi-line output. At any given time not more than one output from the level decoder is "true". The "true" output is clocked once per conversion to provide an input pulse to an associated electronic pre-counter coupled to the appropriate decoder output.

A pre-counter is provided for each torqueband. When the count capacity of the pre-counter is reached a pulse is transferred to the corresponding readout. By using pre-counters, the conversion rate of the ADC may be set as high as required to accommodate the requisite signal bandwidth, and at the same time the output pulse rate may be made sufficiently low to be within the speed capability of the readouts and to provide sensible increments (1 second used) of integrated time for the readout counters.

An electromechanical readout having a decimal indication similar to that for a conventional automobile odometer is used. The readouts increment by one each time their coils are energized.

Other systems of storing totalized times over long periods were considered (e.g. core memory, MOS memory, etc.) but it was felt that the electromechanical readout was the best in this instance because:

(i) Totalized time readings are almost indestructible and no standby current is required for storage or display after a flight;

(ii) Totalized time can be easily read at any time without the need for ancillary display equipment;

(iii) The system was required to accommodate only one channel of torque data the overall storage requirement and the data rate requirement were well within the capacity of an electromechanical readout.

Regulated outputs of ± 15 V and $+5$ V are obtained from supply units using 115 VAC 400 Hz single phase primary input power from the aircraft main alternator supply. Readouts and associated driver circuits are powered directly from the aircraft 28 V DC supply.

Transfer of the pre-counter output pulses to the readout coils is achieved via optical isolators. Internal circuit common and readout common are thereby isolated. Best performance however was achieved with the input common connected to chassis which was in turn bolted to aircraft frame. One major advantage resulting from the use of the isolators under these circumstances is that DC supply currents are prevented from flowing back to the primary power source via the instrumentation chassis.

Hardware for torque load spectrum indication in Wessex Mk. 31B operated by RAN comprises two major units:

(i) Transducer which, as indicated earlier, is mounted in the port side lower engine bay;

(ii) Instrumentation unit (called "Torque Analyser") mounted on a shelf on the port side of the rear cabin compartment.

Interwiring as indicated in Figure 2 has been installed in several aircraft to enable input power and the transducer output to be coupled to the Analyser.

3. DETAILED DESCRIPTION OF LOAD SPECTRUM INDICATOR

3.1 Transducer

As indicated earlier (Sec. 1) the transducer needs to be a pressure type with response down to zero frequency. In the Wessex Mk. 31B helicopter 100% torque has been nominally set to correspond to a torquemeter pressure of 440 psi (lb. in.$^{-2}$) or 3034 kPa. Pressure readings in excess of that corresponding to 100% torque are possible.

A Bell and Howell Model 4-366 strain gauge type transducer (Fig. 3) was adopted for the present application. The unit chosen is a sealed gauge type (i.e. gauge pressure on one side of diaphragm is sealed in at the time of manufacture) with full scale of 500 psi or 3447 kPa. This transducer has the following salient characteristics:

(i) 10 VDC rated excitation;

(ii) 350 ohm nominal bridge resistance;

(iii) 40 mV nominal full scale output;

(iv) Natural frequency above 15,000 Hz;

(v) Combined hysteresis and non-linearity less than $\pm 0 \cdot 5\%$ of full-scale output;

(vi) Compensated temperature range 0 to 120°C;

(vii) Operating temperature range −54 to 120°C;

(viii) Designed to operate in severe airborne environment (high vibration, shock or steady acceleration).

Bridge excitation is obtained from a stable voltage reference supply (Sec. 3.2.2) included in the Torque Analyser. A single 4-wire connection is used (Fig. 2). Cable resistance introduces a change in transducer output of less than $0 \cdot 2\%$ of full scale (18 SWG conductors used). If necessary this change can be allowed for at the time of calibration.

Torquemeter pressure varies virtually linearly with developed torque. Because of the good linearity of the transducer characteristic its output will vary almost linearly with torque. Such a linear characteristic is very desirable for the Mark 1 equipment for which the transducer output is effectively divided up into a number of equal width bands (which can be combined together if desired). Translation into equal width torquebands is desirable.

The band separator circuit detailed in Sec. 5 and that used for the Mark 2 equipment can cope much better with non-linear transducer outputs which could arise in other applications.

3.2 Torque Analyser

3.2.1 General

The Torque Analyser is constructed as a single instrumentation item which may be "hard" mounted in a helicopter. Total volume of the Analyser is $5 \cdot 44 \times 10^{-3}$ m^3 approximately (125 mm × 145 mm × 300 mm) and weight is 6 kg. As space did not present any significant limitation in this application the unit has not been designed for minimum size.

Ten non-resettable 6-digit readouts mounted behind the front panel of the analyser (Fig. 4) give readings of the integrated time in seconds for which the torque has fallen within the limits ascribed (Sec. 3.2.5) to each band.

Two supply units mounted at the rear of the analyser (Fig. 5) provide ± 15 V and $+5$ V regulated outputs respectively. Measured current drawn from these supplies is about 60 mA from the $+15$ V and -15 V supplies and $1 \cdot 35$ A from the $+5$ V supply. Current demand from aircraft 115 VAC supply is about 200 mA and that from the 28 VDC supply is about 80 mA average.

Circuits internal to the analyser are mounted on plug-in printed circuit boards. Seven slots

are provided of which six are used and one is spare. Defining the card slots as A to G, where card A is mounted nearest the rear of the unit, the circuit breakdown as defined in the following table results.

Board	Functional Description
A	Clock and Pre-amplifier
B	Spare
C	Torque Band Separator
D	Quad Pre-counter (for Bands 9 and 10, other two not used)
E	Quad Pre-counter (for Bands 5 to 8)
F	Switch-on Delay Circuit
G	Quad Pre-counter (for Bands 1 to 4)

In the following sections, circuit details will be given for each board. Complete information on the components used and the system of labelling adopted for the circuits are given in Appendix 1. Details of interconnections between printed circuit boards and other interwiring within the analyser are given in Appendix 2. As indicated earlier interconnections external to the analyser are given in Figure 2.

3.2.2 Reference Supply for Transducer Bridge Excitation

The reference supply circuit for the transducer is included on printed circuit board A (Clock and Pre-amplifier) for which circuit details are given in Figure 6.

As the output of a strain gauge bridge is proportional to bridge excitation it is essential that good stability is provided. In particular the change with temperature should be minimized.

A balanced (± 5 V) supply providing 10 V total excitation is employed. Such a balanced supply sets the common mode bridge output voltage to zero approximately. With this arrangement the output of the amplifier (Sec. 3.2.3) is virtually unaffected by any changes in amplifier common mode rejection with temperature.

Regulator Q1 and associated components provide the $+5$ V excitation output; regulator Q3 and associated components provide the -5 V excitation. Reference diodes CR1 and CR2 enable good temperature stability to be achieved. In one of the Torque Analyser units tested the variation in reference supply with temperature was found to be about 0·6% over the temperature range -5 to $+50$°C.

Current drawn by the transducer from each supply is about 30 mA.

3.2.3 DC Amplifier and Low Pass Filter

A two-stage amplifier (Fig. 6) comprising Q5, Q6 and associated components is used.

The first amplifying stage incorporating Q1 has differential input, fairly low drift with temperature, high CMRR (common mode rejection ratio) and is capable of fairly high closed loop gain over the frequency range of interest. In this application an overall gain of about 330 is typically required of which the first stage typically contributes a gain of about 190.

The second amplifier stage incorporating Q6 is connected as a summing amplifier to allow the introduction of a large zero shift. For the initial settings used for the Torque Analyser the amplifier is required to provide zero output when 35% rated torque is applied, hence the need for the large zero shift. Potentiometers R9 and R13 (Fig. 6) allow amplifier zero and gain respectively to be trimmed to the exact values required. Initially the gain has been trimmed to provide $+10 \cdot 00$ V output for an applied pressure equivalent to 115% rated maximum torque.

An examination of the torquemeter pressure signal in a number of Wessex Mk. 31B aircraft revealed the presence of a high level component at about 130 Hz frequency. The amplitude of this component increased with torque and typically had a value of about 50 psi (or 34·5 kPa) RMS at 100% torque setting (440 psi). Comparison[1] with an output directly measured from a

strain gauge fitted to the output shaft of the engine reduction gearbox revealed that there was no torque component at this frequency. Flexing of the annulus gear (in the engine reduction gearbox) at 3 times output shaft revolution rate (there are 3 planetary gears) was established at the origin of the 130 Hz component. To prevent incorrect totalizing of the torque load data it is essential that the 130 Hz component be greatly attenuated ahead of the ADC.

Rotor blade passing frequency is about 15 Hz for the Wessex Mk. 31B. A true component of torque variation occurs at this frequency. It was decided that a low-pass filter having virtually no attenuation at 15 Hz and about 40 dB (decibel) attenuation at 130 Hz would satisfy the requirements of the present application. A filter which provides 3 dB attenuation at about 25 Hz frequency has been adopted.

A filter comprising a simple low-pass section in the forward path and a resistor-shunt bridged-T network in the feedback path of the second amplifier is used. To allow the characteristics of the amplifier and filter to be defined the simplified circuit of Figure 7 has been drawn.

Using the designations defined in Figure 7 we may write the following expressions which apply at DC:

$$e_2 = -\left(1 + \frac{50\,000}{R_1}\right) e_1 \tag{1}$$

$$e_3 = -R_5\left(\frac{e_2}{R_3 + R_4} + \frac{V_R}{R_2}\right)$$

$$= \frac{R_5}{R_3 + R_4}\left(1 + \frac{50\,000}{R_1}\right) e_1 - \frac{R_5}{R_2} V_R \tag{2}$$

where the value of R_1 is expressed in ohm.

The overall gain is given by the coefficient

$$\frac{R_5}{R_3 + R_4}\left(1 + \frac{50\,000}{R_1}\right)$$

and the zero shift term (referred to the output) by $-\frac{R_5}{R_2} V_R$ where V_R is the reference supply voltage (derived from the transducer positive excitation generator).

Typical values (Fig. 6 and Appendix 1.1) are:

$$R_1 = 270$$

$$R_2 = 54\ \text{K}$$

$$R_3 + R_4 = 28\ \text{K}$$

$$R_5 = 49{\cdot}5\ \text{K}$$

$$V_R = 5{\cdot}00\ \text{V}$$

for which $e_3 = 329\, e_1 - 4{\cdot}58$ volt.

Additional components C_1, C_2, C_3 and R_6 added for filtering purposes in no way affect the DC gain. If the DC term introduced via R_2 in the output stage is ignored it can be shown that the transfer function of the filter stage is given by:

$$\frac{e_3}{e_2} = \frac{R_3}{R_1 + R_2}\left\{\frac{1}{1 + j\omega\dfrac{C_1 R_3 R_4}{R_3 + R_4}}\right\}\left\{\frac{1}{1 - \dfrac{\omega^2 C_2 C_3 R_5 R_6}{1 + j\omega(C_2 + C_3)R_6}}\right\} \tag{3}$$

where ω is the radian frequency.

The two frequency dependent terms in the above equation define the responses of the input and the feedback filter sections respectively. Hence the response of each filter section may be considered separately and the overall response obtained by multiplying the individual responses together.

The overall rationalized gain A_R (considered to be unity at DC) is given by:

$$A_R = \frac{1}{\sqrt{\left\{1 + \left(\frac{\omega C_1 R_1 R_2}{R_1 + R_2}\right)^2\right\}}} \cdot \sqrt{\left\{\frac{1 + \{\omega(C_2 + C_3)R_4\}^2}{(1 - \omega^2 C_2 C_3 R_3 R_4)^2 + \{\omega(C_2 + C_3)R_4\}^2}\right\}} \quad (4)$$

It is of interest to define the frequency at which the second term peaks and the relative amplitude of the peak.

If we define

$$A = \{(C_2 + C_3)R_4\}^2 \quad (5)$$

$$\text{and } B = C_2 C_3 R_3 R_4 \quad (6)$$

it can be shown that the radian frequency ω_0 of the peak is given by:

$$\omega_0{}^2 = \frac{1}{A}\left\{\sqrt{1 + \frac{2A}{B}} - 1\right\} \quad (7)$$

and the amplitude of the peak by:

$$A_{R0} = \sqrt{\left\{\frac{1 + A\omega_0{}^2}{(1 - B\omega_0{}^2)^2 + A\omega_0{}^2}\right\}} \quad (8)$$

If it can be assumed that $A \ll B$ then the following approximate expressions apply:

$$\omega_0{}^2 \approx \frac{1}{B} \quad (9)$$

$$A_{R0} \approx \sqrt{(1 + B/A)} \quad (10)$$

Some variation in the values of R_3 and R_4 (Fig. 7) arises in the two Torque Analysers which have been commissioned. For the first analyser commissioned the following values apply:

$$R_3 = 3 \cdot 9 \text{ K}$$

$$R_4 = 24 \text{ K}$$

$$R_5 = 49 \cdot 5 \text{ K}$$

$$R_6 = 4 \cdot 7 \text{ K}$$

$$C_1 = 4 \cdot 2\ \mu\text{F}$$

$$C_2 = C_3 = 0 \cdot 45\ \mu\text{F}.$$

Substituting the appropriate values in equations 7 to 10 yields:

	Frequency (f_0) of Peak*	Relative Amplitude of Peak
Exact Solution (Eqns. 7–8)	21·5 Hz	1·96
Approx. Solution (Eqns. 9–10)	23·1 Hz	2·02

* Where $f_0 = \frac{\omega_0}{2\pi}$.

It is to be noted that the approximate solution provides figures very close to those yielded by the exact solution.

In Figure 8 the measured response of the individual filter sections together with that for the composite filter are drawn. It is to be observed that the measured characteristic of the bridged-T filter agrees closely with the exact solution predicted above.

The salient characteristics of the low-pass filter are summarized below:

(i) Frequency at which the response of the input filter section (considered alone) is −3 dB relative to the DC value; 11·3 Hz

(ii) Frequency of peak in the response of the bridged-T section (considered alone);	24·3 Hz
(iii) Relative amplitude of peak in the response of the bridged-T filter;	1·96
(iv) Frequency at which the overall response is down −3 dB relative to the DC value;	25 Hz
(v) Relative response (compared with that which applies at DC) of overall filter at 130 Hz;	0·011 (1·1%)

At a gain setting of about 200 the first amplifier stage incorporating Q5 (Fig. 6) provides a response which is typically flat to about 500 Hz, so any filtering action in that stage can be ignored in this application.

Some zero offset is inherent in both the strain gauge transducer and the first amplifier stage. The overall zero adjustment by way of R9 (Fig. 6) takes account of these.

3.2.4 Clock Generator

The clock generator comprising Q7 to Q9 (Fig. 6) and associated components is required to initiate conversions in the ADC (Sec. 3.2.5) and to enable digitization of the integrated time for which the torque falls within each band. Any timing errors will produce proportional readout errors. It is therefore essential that fairly accurate timing be provided.

A crystal oscillator operating at 1 MHz frequency and a counter time-base circuit Q7, set to provide a division factor of 1000, produces the System Clock Output (1000 Hz) used to initiate conversions in the ADC. Although the crystal oscillator and associated circuits provide a timing accuracy better than required such a circuit configuration has been chosen because it is robust, simple, relatively cheap and requires very little environmental proving (e.g. temperature stability).

Decade counters Q8 and Q9 are cascaded to provide an Output Pulse Clock at 10 Hz rate. That output is used (Sec. 3.2.6) to set the duration of the switch-on pulses for the electromechanical readouts.

3.2.5 Torque Band Separator

Full circuit details of the torque band separator are given in Figure 9. It incorporates the ADC and Level Decoder shown in the block schema of Figure 1.

The ADC (Q2) converts the analogue output of the DC amplifier, which ideally is proportional to torque, into digital form which can be readily decoded into bands. Generally manufacturers do not make ADC's with less than 8-bit resolution so such a converter was used (although the full 8-bit resolution was not required for the particular decoder used).

Characteristics of the successive approximation type ADC used are as follows:

Resolution	8-bit
Full Scale	0 to +10·0 volt
Code	Pure Binary
Conversion Time	4 microsecond.

Conversion rate for the ADC needs to be high enough to allow torque fluctuations at the maximum frequency of interest to be followed. In the present application the DC amplifier will admit components up to 25 Hz with little attenuation. The chosen sampling rate of 1000 Hz will readily allow components in the frequency band of interest to be followed, and could probably accommodate components having about an order higher frequency.

Decoding the ADC output into bands can be achieved in many ways. In the band separator used in the Mk. 1 Analyser the four most significant ADC output bits (B0 to B3) are decoded by a 4-line to 16-line decoder Q6. In addition the extremes of the range 11111111 and 00000000 are detected and processed to provide over-range and under-range outputs respectively. Open collector NAND gates Q8 to Q11 may have their outputs appropriately joined so that the width of the bands may be increased in integral increments of $\frac{1}{16}$ of the range of interest. Dotted links (Fig. 9) indicate the original settings.

As indicated in Section 3.2.3 zero and gain potentiometers in the analogue amplifier are trimmed to provide the ADC inputs indicated below:

Applied Pressure (psi)	Equivalent Torque (%)	ADC Input Voltage
154	35	0·00
506	115	10·00

Details of the original torqueband allocations together with the ADC outputs are provided in the following table:

Band No.	ADC Input Range (volt)	Equivalent Torque Range		ADC Output							
		%	psi	B0	B1	B2	B3	B4	B5	B6	B7
10	Above 9·961	Above 114·7	Above 504·625	1	1	1	1	1	1	1	1
9	9·375 → 9·961	110 → 114·7	484 → 504·625	1	1	1	1	×	×	×	×
								except 1111			
8	8·750 → 9·375	105 → 110	462 → 484	1	1	1	0	×	×	×	×
7	8·125 → 8·750	100 → 105	440 → 462	1	1	0	1	×	×	×	×
6	7·500 → 8·125	95 → 100	418 → 440	1	1	0	0	×	×	×	×
5	6·250 → 7·500	85 → 95	374 → 418	1	0	1	×	×	×	×	×
4	5·000 → 6·250	75 → 85	330 → 374	1	0	0	×	×	×	×	×
3	3·750 → 5·000	65 → 75	286 → 330	0	1	1	×	×	×	×	×
2	1·250 → 3·750	45 → 65	198 → 286	0	1 or 0	0 or 1	×	×	×	×	×
1	Below 1·250	Below 45	Below 198	0	0	0	×	×	×	×	×

"×" means either "1" or "0".

It is to be noted that since output 11111111 is regarded as an over-range, band 9 is only $\frac{15}{16}$ the width of band 8. Full width together with over-range and under-range capability could easily be achieved by using less of the available ADC range. If the range of interest was confined to $\frac{1}{4}$ the dynamic range of the ADC (i.e. 2·5 V) output bits B0 and B1 could be used to detect in-range and out-of-range signals.

When the load pulse (generated at the output of Q1C) is true (which occurs for a duration of about 400 nanosecond at 1000 times per second) a negative going pulse will be generated on only one of the outputs PC-1 to PC-10 which form the inputs to the pre-counters (Sec. 3.2.6). Hence each pulse on any particular output may be interpreted as an indication that the torque has had a value between the levels ascribed to the particular output for a time interval of $\frac{1}{1000}$ second. Totalizing the number of pulses will give the integrated time that the torque falls within the relevant band.

For the band ranges initially chosen contributions in the over-range band (band 10) are unlikely to occur but significant contributions will occur in the under-range band (band 1). With this arrangement complete coverage of all possible torque values is provided so that the aggregate of all contributions should be a measure of and, for proper system functioning, should check with operating time calculated by other means.

Light emitting diodes CR1 to CR6 provide indication of the logic states of the four least significant ADC outputs, the over-range output and the under-range output.

The Mk. 2 equipment makes use of a ROM (read only memory) which allows band limits to be selected anywhere within the 256-bit range of the ADC and allow band limits to be altered via the insertion of a newly programmed ROM. A simple extension of the band separator to the arrangement indicated in Section 5 could provide a replacement for the circuit used in the Mk. 1 Analyser.

3.2.6 Pre-counter and Readout

The circuit of the quad pre-counter is drawn in Figure 10. Three such quad pre-counters incorporated on different printed circuit boards (Appendix 2) are used. However power supply connections to the board have been arranged in such a way that the two unused pre-counters (10 only required) do not draw supply current. As the individual pre-counters are identical the operation of the one containing Q1 to Q5 and associated components will be considered.

Decade counters Q1 to Q3 form a pre-counter which has a count capacity of 1000. For an initial delay period (Sec. 3.2.7) the Reset input is high and inhibits counting of extraneous pulses at the time power is first applied. Thereafter the Reset input remains low so that counting of pulses transferred via the appropriate PC output (Fig. 9) proceeds normally.

Each time the state of the pre-counter changes from 999 to 000 a negative going pulse, generated via the pulse generator containing Q4, is transferred after a short delay to the input of optical isolator Q5 via the inverter Q21C. The isolator output is coupled to the driving circuit for an associated electromechanical readout (in this case No. 1). Both the driving circuit and the readout are powered directly from aircraft 28 VDC supply whereas the circuits ahead of the isolator are powered from the internal supply in the analyser.

When the pulse output is true (i.e. output of inverter Q21C is low) the input diode in the optical isolator Q5 conducts thus causing the output transistor in the isolator and the output drive transistor TR1 to conduct. When TR1 conducts current is supplied via the EMC-1H and the EMC-1L outputs to electromechanical readout No. 1. When the output of inverter Q21C reverts to the high state both the isolator and the drive transistor revert to the non-conducting state.

It is possible that the output of counter Q3 can remain for long periods in either the low or the high state. The readouts used (Appendix 1.5) are rated for 100% duty cycle so that correct counting should occur if the Q3 counter output were directly coupled to the isolator. However increased current could be drawn from the 28 VDC line and unnecessary heating of the readout coils could result (each coil consumes about 3 watt when continuously energized). For this reason it was decided that a constant duration pulse be generated each time a readout is to be advanced.

The pulse generator utilizes a decade counter (SN7490 type) in a novel configuration. Each time a negative transition occurs on one of its inputs an output pulse having a duration equal to twice the repetition period of an incoming clock is generated after some delay. With such a circuit (repeated 10 times) individual timing components are not needed to set output pulse duration for each readout.

Whenever the "D" output of Q3 switches low Q4 will begin to count cycles of the incoming clock (derived from OP CLK 1 input) but after 5 cycles have been counted Q4 will latch into the zero count state where it will remain until the next time it is reset to the nine state by the pre-counter output. The reset and count state logic sequence for the "clocked" pulse generator is indicated in the following table:

Time sequence	Reset inputs		Counter outputs			
	R_9	R_0 (=A)	D	C	B	A
For time pre-counter output is high (i.e. $R_9 = 1$)	1	0	1	0	0	1
Just after R_9 reverts to "0" but before first clock pulse	0	0	1	0	0	1
At first clock pulse	0	0	0	0	0	1
At second clock pulse	0	0	0	0	1	1
At third clock pulse	0	0	0	1	0	1
At fourth clock pulse	0	0	0	1	1	1
At fifth clock pulse and thereafter till pre-counter switches high again	0	0	0	0	0	0
For time pre-counter output is high (i.e. $R_9 = 1$)	1	0	1	0	0	1

As indicated in the above table the C output of Q4 switches high after two OP CLK pulses have been received since the R_9 reset input reverted to the low state (i.e. since the pre-counter state changed from 999 to 000). The C output remains high for two periods of the clock (i.e. for 0·2 second), then reverts to the low state in which it remains till the next pulse cycle. The 0·2 second duration pulse generated on the C output is inverted and coupled to the readout via the optical isolator and driver.

For each second of totalized time that the torque is within a particular band a pulse will be transferred to the corresponding readout. Hence the readouts register totalized time in seconds that the torque falls within the limits of the specified band for that readout.

3.2.7 Switch-on Delay Circuit

To prevent erroneous counts being registered in the readouts at the time AC power is first applied it is desirable that application of 28 VDC to the readouts be delayed somewhat to allow the regulated outputs ± 15 V and $+5$ V to come up to specification. Further it is desirable that the pre-counters be intially reset to the zero count state so that there is no chance of an output pulse being transferred to a high torqueband readout at this time. Erroneous 1 second contributions to Band 10 for instance could be very misleading and cause unnecessary concern.

A delay circuit (Fig. 11) powered from the $+5$ V regulator output is used. Prior to the application of power, capacitor C1 will be discharged. When AC power is first applied the output of the $+5$ V regulator will rise towards its specified value, the output of comparator Q1 will switch to the low state, and the outputs of NAND buffers Q2A and Q2B will switch high. Under these conditions relay K1 will not be energized.

After a delay period 0·7 (C1)(R1) second approximately (where C1 is expressed in microfarad and R1 in megohm) the output of comparator Q1 will revert to and be maintained thereafter at the high state. As a consequence the output of buffer Q2B will switch low and relay K1 will be energized thus connecting 28 VDC to the readout circuits. For the present circuit the delay is set to 3 seconds approximately.

Buffer output Q2A is used to initially reset all pre-counters to the zero count state.

Diode CR1 allows capacitor C1 to rapidly discharge through the circuits loading the $+5$ V regulator when 115 VAC power is switched off. In that way relay K1 drops out rapidly and erroneous additional counts on the readouts are prevented.

4. PERFORMANCE OF LOAD SPECTRUM INDICATOR

The transducers (Sec. 3.1) are designed for use in an airborne environment and they have performed quite satisfactorily in the two installations presently acquiring data during flight. However some shifts (which rendered a new calibration necessary) were noted in one transducer after about six months operation.

At an early development stage the performance of the electromechanical readouts was checked to establish their suitability with respect to vibration and steady acceleration.

Readouts installed in the final housing ("hard" mounted) were checked over the frequency range 5 to 150 Hz with an applied vibration velocity level of 89 mm/s and a sweep rate of ½ octave per minute (DEF (AUST) 247 Specification for equipment to be installed in helicopters). When tested in each of three mutually perpendicular directions the readouts counted correctly.

No malfunctioning of the readouts occurred when they were subject to a static acceleration of 6G level in any of three mutually perpendicular directions.

The performance of each Torque Analyser was carefully monitored during their respective initial test flights. To check whether the electromechanical readouts performed correctly in the flight environment a separate electronic counter with solid state (light emitting diode) display was used to count "seconds" as generated by the internal timing of the analyser. A flight test lasting about 70 minutes was performed on the first analyser and one lasting about 145 minutes was performed on the second.

The change in the electronic counter reading was compared with the change in the sum of the electromechanical counter readings for a period starting soon after alternator power switch-on and ending just before alternator power stitch-off. For each analyser the change in the electromechanical counter readings was about 3 less than the "seconds" count on the auxiliary electronic counter. Because the pre-counters (Sec. 3.2.6) are initially reset to zero it is to be expected that the change in the electromechanical counter readings will be slightly less than the "seconds" count but should not exceed 7 if it is assumed that there is no contribution on the upper three torque bands. This test proved conclusively that the electromechanical readouts performed without loss or extraneous addition of counts when operated in the flight environment.

The analysers were designed and tested for operation over the temperature range 0 to 55°C, a range considered adequate for the present application. Some shift in the analogue amplifier characteristic with temperature has been observed. Combined zero and sensitivity shift gives rise to an output variation within $\pm 1\%$ of full scale over the temperature range indicated above. Referred to the input $\pm 1\%$ of full scale is equivalent to ± 3 psi (dynamic range is 198 to 506 psi) or $\pm 0{\cdot}7\%$ rated maximum torque. Most of the variations with temperature take place in the first analogue amplifier stage (incorporating Q5 of Fig. 6). Tests have shown that the Mk. 2 equipment is less affected by temperature variations.

Most integrated circuits used in the analysers have specifications guaranteed over the temperature range 0 to 70°C. However more expensive types with specifications guaranteed over the temperature range −55 to 125°C can be used as direct replacements (of same physical dimensions) for these.

Crystal controlled timing frequency (1 MHz nominal) was found to be within $0{\cdot}02\%$ of nominal frequency at 20°C and to vary by $0{\cdot}007\%$ over the 55°C test temperature range. When the analysers were flight tested the analyser timing precision was compared with that of a stopwatch for flights of over an hour in the case of each analyser. For both analysers the reading differed by only 1 second over that period. Such timing accuracy is considered to be more than adequate.

Overall system linearity (readout counter changeover point versus applied pressure) has been checked using a dead weight pressure calibrator providing $0{\cdot}25$ psi resolution over the pressure range of interest (198 to 506 psi). All changeover points were within $0{\cdot}25$ psi [or $0{\cdot}06\%$ of rated maximum torquemeter pressure (440 psi)] of the theoretical points based on an exact straight line relationship. Linearity of the system of converting torque to the analogue pressure has not been investigated.

The torque analyser provides a fairly low noise measuring system. Before the 25 Hz filter (Sec. 3.2.3) was incorporated the noise level measured at the ADC input with the transducer not connected to the torquemeter pressure line but with aircraft engines operating normally was about $0{\cdot}1\%$ full scale RMS with the major component at 400 Hz. Following the introduction

of the filter noise other than that arising from extraneous pressure fluctuations was totally negligible. It was not possible to observe any 130 Hz noise component on the ADC input at this stage because of other fluctuations (arising mainly because of genuine torque variations). At 100% torque loading the true signal variations observed at the ADC input typically amount to 0·3 V or 3% of full scale ADC input.

As mentioned in Section 3.1 a sealed gauge type transducer has been used to measure torquemeter pressure. In such transducers atmospheric pressure sealed in at the time of manufacture is applied to one side of the diaphragm. Thus these transducers tend to act like absolute transducers. Changes in atmospheric pressure with varying ambient conditions and with altitude will give rise to some errors in the measurement of pressure since the pressure of interest is that of the torquemeter relative to atmospheric pressure. In the worst case, say at an altitude of 3000 m or 10,000 ft the error could be about 4·5 psi. Vented gauge types are used in the Mk. 2 system.

The torque load spectrum indicators (incorporating analyser and transducer) have been gathering torque load data since July and October 1975 respectively. At the end of each flight the analyser readings are entered on special data sheets. Pilots also log flying time on these sheets. Agreement between times logged by pilots and the total change in the electromechanical counter readings has been noted for all data sheets received to this stage.

Overall performance of the load spectrum indicators installed in Wessex Mk. 31B aircraft is considered to be satisfactory.

5. ANALYSER CIRCUIT IMPROVEMENTS

Improvements, the chief ones of which are summarized below, apply for circuits used in the Mk. 2 equipment:

(i) Incorporation of analogue amplifying system less affected by temperature variations;

(ii) Use of a dual purpose band separator which will not only allow the integrated time in seconds for which torque falls within specified bands to be indicated, but alternatively the total number of level exceedances or fatigue cycles which have occurred (if an alternative link is used on the band separator circuit);

(iii) Use of a versatile pre-counter in which counting for all bands is done using a single counter utilized on a time shared basis;

(iv) Overall reduction in the number of components and the number of printed circuit boards (reduced from six to four).

Interwiring changes were necessary for the Mk. 2 equipment.

One very simple modification which could be used as a direct replacement for the Mk. 1 band separator with no interwiring changes is drawn in Figure 12. A suitably programmed plug-in ROM (read only memory) is used to define the changeover points for each torqueband. The 8-bit ADC output is used as the address input to the ROM which allows 256 4-bit memory locations to be accessed. Addresses 0 through 9 (for torqueband counters 1 to 10) are stored in batches of the 4-bit memory locations so as to define the limits for each torqueband. With this form of band separator the particular program summarized in the following table would yield a torqueband distribution similar to the one used at present (Sec. 3.2.5):

Equivalent Torque Range	Torqueband "X"	Range of ROM Memory Locations "Y" in which Address X is Programmed
Above 115%	$X = 10$	$254 \leqslant Y \leqslant 255$
110 → 115%	$X = 9$	$236 \leqslant Y \leqslant 253$
105 → 110%	$X = 8$	$218 \leqslant Y \leqslant 235$
100 → 105%	$X = 7$	$200 \leqslant Y \leqslant 217$
95 → 100%	$X = 6$	$182 \leqslant Y \leqslant 199$
85 → 95%	$X = 5$	$146 \leqslant Y \leqslant 181$
75 → 85%	$X = 4$	$110 \leqslant Y \leqslant 145$
65 → 75%	$X = 3$	$74 \leqslant Y \leqslant 109$
45 → 65%	$X = 2$	$2 \leqslant Y \leqslant 73$
Below 45%	$X = 1$	$0 \leqslant Y \leqslant 1$

To set up the system for the torque ranges indicated in the above table zero and sensitivity adjustments in the analogue amplifier would have to be performed.

Any new set of torqueband limits could be introduced simply by plugging in a new ROM with suitable programme. Band changeover points could be located anywhere in the range of interest but with maximum resolution of about 0·4% (equivalent to 1 in 250 bits).

In applications other than that described in this report the transducer characteristic may have significant non-linearity. With this band separator the overall linearity may be improved to ±0·4% of full scale by suitably programming the ROM according to the known calibration characteristic.

BCD to decimal decoder Q4 provides a 10-line output for use with the pre-counters (Sec. 3.2.6).

Component count for the band separator is three intergated circuit devices, one ADC and minor components. This represents quite a saving relative to the band separator circuit of Figure 9.

6. CALIBRATION AND TEST PROCEDURES

6.1 General

Although only two analysers have been put into service appropriate modifications (a special pressure fitting for the transducer and incorporation of additional wiring) have been performed on a number of Wessex Mk. 31B aircraft to allow fitment of analyser and transducer. Analysers and associated transducers are transferred from one aircraft to another from time to time in a way which tends to maximize the amount of torque load data collected. Whenever an analyser and transducer are transferred to a different aircraft a functional checkout is performed on the system.

To facilitate the performance of a functional check on the analyser, and also on the transducer to a limited extent, a Torque Analyser Function Tester (TAFT) described in detail in Section 6.3 has been made at these laboratories.

System calibration requires the use of a dead weight pressure calibrator capable of applying pressures in the range 198 to 506 psi (for the original torqueband allocation). Pressure resolution over the range must be at least 1 psi.

Convenient checkout of the system calibration can be performed periodically (without the need to apply pressure to the transducer) using a Torque Analyser Calibration Tester (TACT) described in detail in Section 6.4. This unit is matched to the previous system pressure calibration and indicates in 1 psi increments in the range ±7 psi any departure from the previous calibration.

Because function and calibration testing with TAFT and TACT respectively are normally performed with the equipment *in situ* in the aircraft with engines off (i.e. no alternator power available for the Torque Analyser) an auxiliary supply is essential for ground testing. For convenience a portable static inverter power supply (Sec. 6.2) powered from 28 VDC (nominal) has been produced for this purpose.

6.2 Static Inverter Power Supply

The Torque Analysers require both 115 VAC (57 to 440 Hz) and 28 VDC. Normally 115 VAC 400 Hz is obtained from the transmission driven alternator. No current is drawn from the 28 VDC line until 115 VAC is applied.

To allow the analysers to be operated during ground checks (when the alternator is not driven) a static inverter power supply (Fig. 13) providing 115 VAC 400 Hz output is used. The input requirement for this supply is 22 to 30 VDC at about 2·5 A (when loaded with an analyser). The supply is interposed (Fig. 14) between the analyser power input cable and the mating receptacle on the analyser.

Power for the analysers during ground checks is drawn from aircraft DC supply boosted either from a mains rectifier supply or engine driven mobile generator. Operation from aircraft battery is not recommended because the combined effect of low battery voltage and drops in the aircraft power wiring may cause the analyser to malfunction because of inadequate supply voltage.

Aircraft supplies boosted by a mains rectifier or engine driven generator (mobile type) exhibit a fair amount of ripple and noise. To reduce the effect of these, a filter (Fig. 14) has been incorporated in the inverter supply. With full load current (about 2·5 A) flowing through the filter the resulting output ripple is normally less than 1 V peak to peak.

6.3 Torque Analyser Function Tester

To perform a function check using the tester:

(i) the transducer must be connected in the normal manner;

(ii) pressure must not be applied to the transducer (i.e. engines would normally be off).

Power is applied to the analyser using the static inverter power supply in the configuration depicted in Figure 14. The Torque Analyser Function Tester (Fig. 15) is interposed (Fig. 16) between the transducer output cable and the mating receptacle on the analyser.

The tester applies a shunt resistance across one arm of the strain gauge bridge incorporated in the transducer. The value of shunt resistance is switch selectable (Fig. 17) and arranged to simulate input pressures which fall within each torqueband (1 to 10). Shunt resistors are mounted on a plug-in printed circuit card accessible when the bottom cover is removed from the tester. Because the characteristics of the two transducers at present used are similar the same plug-in card can be used to functionally check both analyser installations. Initially the shunt resistors have been chosen to check the pressure ranges indicated in the following table. If the pressure ranges are changed at some future date from those tabulated a new function tester card will be required.

Setting of Band Switch	Torqueband Checked	Equivalent Pressure Range (psi)
0	1	Ext. Shunt Posn.
1	1	Below 198
2	2	198–286
3	3	286–330
4	4	330–374
5	5	374–418
6	6	418–440
7	7	440–462
8	8	462–484
9	9	484–504·6
10	10	Above 504·6

The tester case should not touch aircraft frame (hence the reason for using insulating feet)

when the tester is in use. Isolation from aircraft frame is merely to reduce ground loop noise and no damage will result if the tester case is electrically connected to aircraft frame.

The Function Tester checks that:

(i) the transducer strain gauge bridge is intact;

(ii) all circuits and all readout counters in the analyser are functional.

The Function Tester does not check that pressure applied to the transducer produces an equivalent strain. To functionally check the complete system some test pressures would have to be applied with the engines running or alternatively a system pressure calibration using a dead weight tester could be performed. Checkout with pressure applied is not required for routine functional checks.

For convenience in the performance of more detailed checks the transducer excitation and the transducer output are brought out on terminals and connector respectively. With the thumbwheel switch set to position 0 the bridge output may be controlled by an external shunt connected via the EXT SHUNT connector.

6.4 Torque Analyser Calibration Tester

The Torque Analyser Calibration Tester (Fig. 18) applies a shunt resistance across one arm of the strain gauge bridge incorporated in the transducer. The value of shunt resistance is switch selectable and accurately trimmed, at the time of the previous system pressure calibration, to simulate torqueband changeover (i.e. Band 1–2 to Band 9–10) pressures. In addition top panel mounted pushbuttons allow the equivalent applied pressure to be changed in increments of 1 psi in the range ± 7 psi relative to the calibration pressure. Complete circuit details of the calibration tester are given in Figure 19.

Precision fixed resistors and trimming potentiometers (one for each band changeover) are mounted on a plug-in printed circuit board. A separate board is required for each transducer and any change in band changeover pressures would necessitate a change in the resistance components on the board.

Primarily the calibration tester is designed to provide a very simple method of checking how accurately the calibration is maintained over long periods. The pressure to strain relationship for the transducer is not checked, but any changes in the bridge characteristics or in the circuit components in the Torque Analyser will be immediately apparent if such changes give rise to variation in the calibration characteristic.

To perform a calibration check using the tester:

(i) the transducer must be connected in the normal manner;

(ii) pressure must not be applied to the transducer (i.e. engines would normally be off when the calibration is checked with the equipment installed in the aircraft).

Power is applied to the analyser using the static inverter power supply in the configuration depicted in Figure 14. The calibration tester is interposed between the transducer output cable and the mating receptacle on the analyser.

To perform a calibration check the toggle switch on the top panel is turned "ON". The "OFF" position allows an external shunt to be applied via the EXT SHUNT connector without any parallel resistance being applied by the tester. TDR EXCIT and TDR OUTPUT connectors allow the excitation and the transducer output respectively to be monitored if desired.

With all six INCR pushbuttons on the top panel in their normal (not depressed) state the tester produces an output equal to that which would be obtained if the equivalent band changeover pressures (indicated in the following table as a function of SELECTOR switch position) were applied to the transducer.

Selector Switch Position	Torqueband Changeover	Equiv. Pressure Calibration (psi)
0	Not Applicable	7
1	1–2	198
2	2–3	286
3	3–4	330
4	4–5	374
5	5–6	418
6	6–7	440
7	7–8	462
8	8–9	484
9	9–10	504·6

The checkout procedure is best illustrated with the aid of an example. Assume the 5–6 torqueband changeover is to be checked in relation to the previous pressure calibration. Selector switch position 5 is first chosen. Assume that with no buttons depressed output is obtained only on the band 5 readout. It follows that the actual changeover pressure must be higher than the calibration pressure. Positive INCR pushbuttons, starting at +1, are depressed until an output is obtained only on the band 6 readout. If an output is obtained only on the band 5 readout when the +2 pushbutton is depressed and only on the band 6 readout when the +1 and +2 pushbuttons are simultaneously depressed it may be concluded that the calibration has shifted between +2 and +3 psi. All remaining band changeovers may be similarly checked.

The tester case should not touch aircraft frame (hence the reason for the insulating strips on the base) when the tester is in use. Isolation from aircraft frame is merely to reduce ground loop noise and no damage will result if the tester case is electrically connected to aircraft frame.

A flexible printed circuit layout allows the value of transducer shunt resistance to be conveniently set to provide the required outputs. Each shunt resistance (Fig. 19) may utilize a series or a parallel combination of fixed resistors. The transducer manufacturer indicates the shunt resistance value which produces a bridge output equal to 80% of full range pressure.

Define P_C = 80% pressure (400 psi for the transducer used)

R_{SC} = 80% shunt calibration resistance

P = arbitrary pressure

R_S = value of shunt resistance having same effect as the application of pressure P.

R_S may be calculated from:

$$R_S = \frac{400}{P} R_{SC}$$

The transducer associated with the first analyser commissioned had a value of R_{SC} equal to 27·98 kilohm (k). For that transducer the resistance values (where $R1$ for instance represents the total shunt resistance presented between pin 18 and 15 of J6 (Fig. 19) and thus includes the effect of $R1$–1, $R1$–2 and $R1$–3, and so on for $R2$ etc.) given in the following table apply:

Selector Switch Position	INCR Buttons Depressed	Equiv. Pressure (psi)	Total Shunt Resistance	
			Legend (Fig. 19)	Value (k)
0	−2, −4	1	*R*1	11192
0	−1, −4	2	*R*2	5596
0	−2, −2	4	*R*3	2798
1	NIL	198	*R*4	56·53
2	NIL	286	*R*5	39·13
3	NIL	330	*R*6	33·92
4	NIL	374	*R*7	29·93
5	NIL	418	*R*8	26·78
6	NIL	440	*R*9	25·44
7	NIL	462	*R*10	24·23
8	NIL	484	*R*11	23·12
9	NIL	504·625	*R*12	22·18
			*R*13	Open Circuit
0	−1, −2, −4, +4	4	*R*14	2798
0	−1, −2, −4, +2	2	*R*15	5596
0	−1, −2, −4, +1	1	*R*16	11192

6.5 Pressure Calibration

Complete system checkout and recalibration is best done with the aid of a dead weight pressure calibrator providing pressure inputs in the range 198 to 506 psi (for initial torqueband settings) adjustable in increments of 1 psi. Although the recalibration may be performed with the equipment installed in the aircraft, but with the transducer disconnected from the aircraft torquemeter pressure line, it is normally more convenient to take the analyser and transducer to the pressure calibration facility. The configuration indicated in Figure 20 has been used for recalibration at the Australian Naval Air Station at Nowra. Cable CBL-1 is made the same type and length as the aircraft wiring and therefore minimizes any errors due to different transducer cables. In any case the interposing of the aircraft wiring between the transducer and the analyser produces a change equivalent to less than 1 psi or 0·2% of transducer full scale pressure.

Recalibration normally involves the trimming of the two potentiometers in the analyser and the nine potentiometers in the calibration tester. A recalibration is recommended if:

(i) The shift in calibration of any band changeover point, as indicated by a test using the calibration tester (Sec. 6.4) amounts to 5 psi or more after the analyser has been switched on for at least 30 minutes.

(ii) Six months have elapsed since the previous calibration was performed;

(iii) The transducer is replaced for any reason;

(iv) The torqueband limits are changed for any reason.

If (iii) or (iv) applies modification to the pre-amplifier board in the analyser and to the calibration tester plug-in board will probably be required.

The analyser may be powered (Fig. 20) from the static inverter supply which requires 28 VDC (nominal) input at about 2·5 A.

A recalibration involves the following steps:

(i) Ambient pressure is noted for future reference (any changes in ambient pressure will give rise to variations in the system calibration because the transducer is a "sealed gauge" type).

(ii) The transducer output voltage is recorded for two extremes of applied pressure (normally 198 and 484 psi which represent the band 1–2 and band 8–9 changeover pressures respectively for the initial band allocation).

(iii) The potentiometers in the calibration tester are adjusted to match the calibration of (ii) at the selected points. Intermediate changeover pressures are simulated after adjustment

of the remaining potentiometers in the tester to provide outputs which lie on a straight line between the two calibration points above. If V_1 and V_8 are defined as the transducer outputs corresponding to the calibration pressures P_1 and P_8 respectively, then the potentiometers in the calibration tester are adjusted, with no pressure applied to the transducer, to provide an output V to simulate a changeover pressure P according to the following relationship:

$$\frac{V - V_1}{P - P_1} = \frac{V_8 - V_1}{P_8 - P_1}$$

$$V = \frac{V_8(P - P_1) + V_1(P_8 - P)}{P_8 - P_1}$$

(iv) The analyser is adjusted to match the calibration tester at two points, normally the band 1–2 and band 8–9 changeovers (selector switch positions 1 and 8 on the tester). Potentiometers "Z" and "G" ("zero" and "gain"), accessible with the top cover removed from the analyser, are adjusted such that equal rate outputs (about 1 count every 2 seconds in each case) occurs on readouts 1 and 2 at the band 1–2 changeover and on readouts 8 and 9 at the band 8–9 changeover. As both changeover points vary with the adjustment of both potentiometers a progressive adjustment and re-checking procedure is required. The G potentiometer has more effect on the 8–9 changeover setting than the 1–2 setting.

7. SUMMARY OF EXPERIMENTAL RESULTS

(*a*) A simple system of indicating totalized time that torque loading falls within each of a number of specified bands is described.

(*b*) Load sensing is via a single transducer and only two adjustments are necessary in setting up the equipment.

(*c*) By using under-range and over-range indication the sum of the totalized times for each band should equal aircraft operating time, a characteristic which allows a simple form of cross checking.

(*d*) An ancillary functional check unit allows the system installed in an aircraft to be rapidly checked periodically.

(*e*) Two sets of equipment which have been installed in helicopters have been successfully used to gather torque load data on a major transmission component.

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(ii) Advice on and selection of a suitable transducer by Mr D. H. Edwards of these laboratories.

(iii) Assistance with the engineering development of the various items of test equipment by Mr B. Drazenovic and Mr R. W. Jackson of these laboratories.

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APPENDICES

1. COMPONENT LISTS

The following tables list the components used in the circuits described in the text. Components have been given an identification label (or legend) consisting of a letter prefix followed by a number. The letter prefix identifies the class of component as indicated in the following table:

Class of Component	Letter Prefix
Resistor	R
Capacitor	C
Diode	CR
Integrated or hybrid circuit	Q
Test Socket	TS
Power Supply	PS
Electromechanical counter	EMC
Chassis mounted plug or socket	J
Transistor	TR
Crystal	XL
Relay	K
Card extractor handle	CEH

The number following the letter prefix identifies the particular component of the specified class.

Resistance and capitance values given in the component lists (and also marked on the circuit diagrams) are given respectively in unit of ohm and picofarad (where $K = 10^3$ and $M = 10^6$ multiplication factors). Thus a capacitance value designated 10 K means 10,000 picofarad and a capacitance designated 6·8 M means $6 \cdot 8.10^6$ picofarad or 6·8 microfarad.

width of the bands may be increased in integral increments of $\frac{1}{16}$ of the range of interest. Dotted links (Fig. 9) indicate the original settings.

1.1 Components for Clock and Pre-amp Board

Legend	Value	Description
R1	33 K	Resistor, fixed, glass-tin-oxide, style RFG5, Electrosil
R2	15 K	As for R1
R3	4·7 K	As for R1
R4	3·3 K	As for R1
R5	4·7 K	As for R1
R6	15 K	As for R1
R7	3·3 K	As for R1
R8	270	As for R1
R9	500	Resistor, variable, wirewound, Bourns 3059L
R10		Value of R10+R11 to be about 54 K for initial torque settings, to be selected to give required adjustment, type
R11		as for R1
R12		Value of R12+R14 to be about 28 K for initial torque settings, to be selected to give required gain, type as for R1
R13	200	As for R9
R14		See note under R12
R15	1·2 K	As for R1
R16	49·5 K	Resistor, fixed, RN55 MIL equiv., ±25 ppm/°C
R17	4·7 K	As for R1
R18	1·2 K	As for R1
R19	27 K	As for R1
R20	8·2 M	Resistor, fixed, Philips CR25
R21	2·7 M	As for R20
C1	2·2 M	Capacitor, fixed, electrolytic, tantalum, Sprague CS13, 35 VW
C2	100	Capacitor, fixed, phenolic dipped ceramic, Vitramon VK23BW series
C3	10 M	As for C1
C4	2·2 M	As for C1
C5	220	As for C2
C6	10 M	As for C1
C7	1 M	As for C1
C8	1 M	As for C1
C9		Value to be selected to provide requisite filter characteristic, for R12 = 3·9 K and R14 = 24 K required C is about 4·2 M, use type as for C1 in "back-to-back" connection
C10	100 K	Capacitor, fixed, phenolic dipped ceramic, Vitramon VK33BW series
C11	27	As for C2
C12	470 K	As for C10
C13	470 K	As for C10
C14	100 K	As for C10
C15	1 M	As for C1
C16	10	As for C2
C17	10	As for C2
C18	100 K	As for C10
C19	100 K	As for C10
C20	100 K	As for C10

$\frac{1}{1000}$ second. Totalizing the number of pulses will give the integrated time that the torque falls within the relevant band.

Legend	Value	Description
CR1		Diode, reference, temperature compensated, LM113, 1·220 V
CR2		As for CR1
CR3		Diode, Zener, 12 volt, 1N4742
TR1		Junction FET, P-channel, 2N4360
TR2		Junction FET, N-channel, 2N3819
Q1		Integrated circuit, positive regulator, LM309H
Q2		Integrated circuit, operational amplifier, LM308H
Q3		Integrated circuit, negative regulator, LM320H
Q4		As for Q3
Q5		Integrated circuit, instrumentation amplifier, LH0036CG
Q6		As for Q3
Q7		Integrated circuit, MOS counter time base circuit, MK5009P
Q8		Integrated circuit, decade counter, SN7490N
Q9		Integrated circuit, decade counter, SN7490N
XL1		Crystal, 1 MHz, HyQ
TS1		Test socket, white, Amp Part No. 3-582118-9
TS1		Test socket, red, Amp Part No. 3-582118-2
TS3		Test socket black, Amp Part No. 3-582118-0

1.2 Components for Torque Band Separator Board

Legend	Value	Description
R1	470	Resistor, fixed, glass–tin–oxide, style RFG-5, Electrosil
R2	470	As for R1
R3	10 K	As for R1
R4	10 K	As for R1
R5	270	As for R1
R6	10 K	As for R1
R7	10 K	As for R1
R8	270	As for R1
R9	10 K	As for R1
R10	10 K	As for R1
R11	270	As for R1
R12	10 K	As for R1
R13	10 K	As for R1
R14	270	As for R1
R15	10 K	As for R1
R16	10 K	As for R1
R17	270	As for R1
R18	10 K	As for R1
R19	10 K	As for R1
R20	270	As for R1
C1	820	Capacitor, fixed, phenolic dipped ceramic, Vitramon VK23BW series
C2	820	As for C1
C3	150 K	Capacitor, fixed, phenolic dipped ceramic, Vitramon VK33BW series
C4	150 K	As for C3
CR1 → CR6		Diode, light emitting, Dialight Corp. Type 521-9167
TR1 → TR6		Transistor, silicon, NPN, 2N3646
Q1		Integrated circuit, hex inverter, SN7404N
Q2		Analogue to digital converter, 8-bit, Datel EH8B-1
Q3		Integrated circuit, quad latch SN7475N
Q4		Integrated circuit, dual 4-input NAND gate, SN7420N
Q5		Integrated circuit, quad 2-input NOR gate, SN7402N
Q6		Integrated circuit, 4-line to 16-line decoder, SN74154N
Q7		As for Q5
Q8 → Q11		Integrated circuit, quad 2-input NAND gate open collector SN7409N
Q12 → Q13		As for Q5
TS1 → TS16		Terminal sockets, Oxley twin pad
TS17 → TS25		Terminal sockets, Oxley single pad

1.3 Components for Quad Pre-counter Board

Legend	Value	Description
R1	180	Resistor, fixed, glass–tin–oxide, style RFG5, Electrosil
R2	4·7 K	As for R1
R3	2·7 K	As for R1
R4	1·2 K	As for R1
R5	1·2 K	As for R1
R6	33	As for R1
R7	180	As for R1
R8	4·7 K	As for R1
R9	2·7 K	As for R1
R10	1·2 K	As for R1
R11	1·2 K	As for R1
R12	33	As for R1
R13	180	As for R1
R14	4·7 K	As for R1
R15	2·7 K	As for R1
R16	1·2 K	As for R1
R17	1·2 K	As for R1
R18	33	As for R1
R19	180	As for R1
R20	4·7 K	As for R1
R21	2·7 K	As for R1
R22	1·2 K	As for R1
R23	1·2 K	As for R1
R24	33	As for R1
C1 → C6	150 K	Capacitor, fixed, phenolic dipped ceramic, Vitramon VK33BW series
Q1 → Q4		Integrated circuit, decade counter, SN7490N
Q5		Integrated circuit, optical isolator, Hewlett Packard 5082-4350
Q6 → Q9		As for Q1
Q10		As for Q5
Q11 → Q14		As for Q1
Q15		As for Q5
Q16 → Q19		As for Q1
Q20		As for Q5
CR1 → CR4		Diode, silicon, OA202
TR1 → TR4		Transistor, silicon, NPN, 2N2102

1.4 Components for Switch-on Delay Circuit Board

Legend	Value	Description
R1	100 K	Resistor, fixed, glass-tin-oxide, style RFG-5, Electrosil
R2	10 K	As for R1
R3	10 K	As for R1
R4	4·7 K	As for R1
C1	47 M	Capacitor, fixed, electrolytic, tantalum, Sprague CS13, 35 VW
CR1		Diode, silicon, OA202
CR2		Diode, silicon, 1N4007
CR3		As for CR1
Q1		Integrated circuit, voltage comparator, LM311D, NS
Q2		Integrated circuit, quad 2-input NAND buffer, SN7437N
K1		Relay, Magnecraft W118DIP-1

1.5 Components for Main Frame

Legend	Description
PS1	Power supply, AC to DC converter, +15 V and −15 V regulated outputs, Tecnetics MR-2150-5
PS2	Power supply, AC to DC converter, +5 V regulated output, Tecnetics MR-1050-8
EMC1 to EMC10	Electromechanical counter, impulse type, 6 digit, Hengstler 0 402 165 with socket
J1	Plug, chassis mounting type, Cannon KPT00A10-6P (F152)
J2	Socket, chassis mounting type, Cannon KPT00A10-6S (F152)
J3 to J9	Connector, printed circuit edge mounting type, double sided, 22 pins per side, Elco 00-6007-044-980-003

2. INTERWIRING DETAILS

Details of all interwiring within the Mk. I Torque Analyser are given in this section.

A summary of the connectors together with their application is given in the following table. Details on the types of connectors (referred to in this section) are given in Appendix 1.5.

Connector	Location	Application
J1	Rear panel	Aircraft input power (115 VAC and 28 VDC) connector
J2	Rear panel	Transducer input/output connector
J3	Internal chassis	Clock and pre-amp board edge connector
J4	Internal chassis	Spare
J5	Internal chassis	Torque band separator board edge connector
J6	Internal chassis	Quad pre-counter (for bands 9 and 10) board edge connector
J7	Internal chassis	Quad pre-counter (for bands 5 to 8) board edge connector
J8	Internal chassis	Switch-on delay board edge connector
J9	Internal chassis	Quad pre-counter (for bands 1 to 4) board edge connector

Details of the interconnections within the analyser are given in the following table:

TORQUE ANALYSER INTERCONNECTION TABLE

Signal Description	Destination											
	PS1 (±15 V)	PS2 (+5 V)	J1 (Pwr. in)	J2 (Tdr. in)	J3 (Clock/ Pre-amp)	J4 (Spare)	J5 (Band Sep.)	J6 (Pre-count/ 9, 10)	J7 (Pre-count/ 5–8)	J8 (Switch-on Delay)	J9 (Pre-count/ 1–4)	EMC (Cntr. Readout)
V_{AA} (+15 V)	+15 V				2	2	2			2		
V_{BB} (−15 V)	−15 V				3	3	3			3		
V_{CC} (+5 V)		+5 V			1, A	1, A	1, A	1, A	1, 2, A, B	1, A	1, 2, A, B	
COM (0V)	0V	0V			21, Y	21, Y	21, Y	21, Y	20, 21, X, Y	21, Y	20, 21, X, Y	
+28 VDC IN			A							7, H		
28 VDC Return			B					10, H	10, 19, H, P		10, 19, H, P	
+28 VDC Out								7, D	7, 16, D, R	9, K	7, 16, D, R	
115 VAC	115 VAC-1	115 VAC-1	C									
115 VAC Ret.	115 VAC-2	115 VAC-2	D									
Chassis Gnd.					21							
+5 V Tdr. excit.				A	19, W							
−5 V Tdr. excit.				B	22, Z							

Signal Description	Destination											
	PS1 (±15 V)	PS2 (+5 V)	J1 (Pwr. in)	J2 (Tdr. in)	J3 (Clock/ Pre-amp)	J4 (Spare)	J5 (Band Sep.)	J6 (Pre-count/ 9, 10)	J7 (Pre-count/ 5–8)	J8 (Switch-on Delay)	J9 (Pre-count/ 1–4)	EMC (Cntr. Readout)
+ Input				D	10*							
– Input				C	9*							
Input Shd.				E	21, Y*							
Analog output					17		L					
Analog Output Com.					Y		K					
System Clk (1000 Hz)					F		17					
Output Pulse Clock					C			6, J	6, 15, J, U		6, 15, J, U	
Pre-cntr Clk 1 (PC-1)							M				C	
PC-2							J				K	
PC-3							H				N	
PC-4							F				V	

Signal Description	Destination											
	PS1 (±15 V)	PS2 (+5 V)	J1 (Pwr. in)	J2 (Tdr. in)	J3 (Clock/ Pre-amp)	J4 (Spare)	J5 (Band Sep.)	J6 (Pre-count/ 9, 10)	J7 (Pre-count/ 5–8)	J8 (Switch-on Delay)	J9 (Pre-count/ 1–4)	EMC (Cntr. Readout)
PC-5							E		C			
PC-6							D		K			
PC-7							4		N			
PC-8							C		V			
PC-9							B	C				
PC-10							$\overline{N}$	K				
Reset (start sync.)								5, 12	5, 12, 14, W	14, R	5, 12, 14, W	
Band 1 Readout											F E	EMC-1H EMC-1L
Band 2 Readout											8 9	EMC-2H EMC-2L
Band 3 Readout											S T	EMC-3H EMC-3L

Signal Description	Destination											
	PS1 (±15 V)	PS2 (+5 V)	J1 (Pwr. in)	J2 (Tdr. in)	J3 (Clock/ Pre-amp)	J4 (Spare)	J5 (Band Sep.)	J6 (Pre-count/ 9, 10)	J7 (Pre-count/ 5–8)	J8 (Switch-on Delay)	J9 (Pre-count/ 1–4)	EMC (Cntr. Readout)
Band 4 Readout											17 18	EMC-4H EMC-4L
Band 5 Readout									F E			EMC-5H EMC-5L
Band 6 Readout									8 9			EMC-6H EMC-6L
Band 7 Readout									S T			EMC-7H EMC-7L
Band 8 Readout									17 18			EMC-8H EMC-8L
Band 9 Readout								F E				EMC-9H EMC-9L
Band 10 Readout								8 9				EMC-10H EMC-10L

* Twisted pair shielded and jacketed cable used.

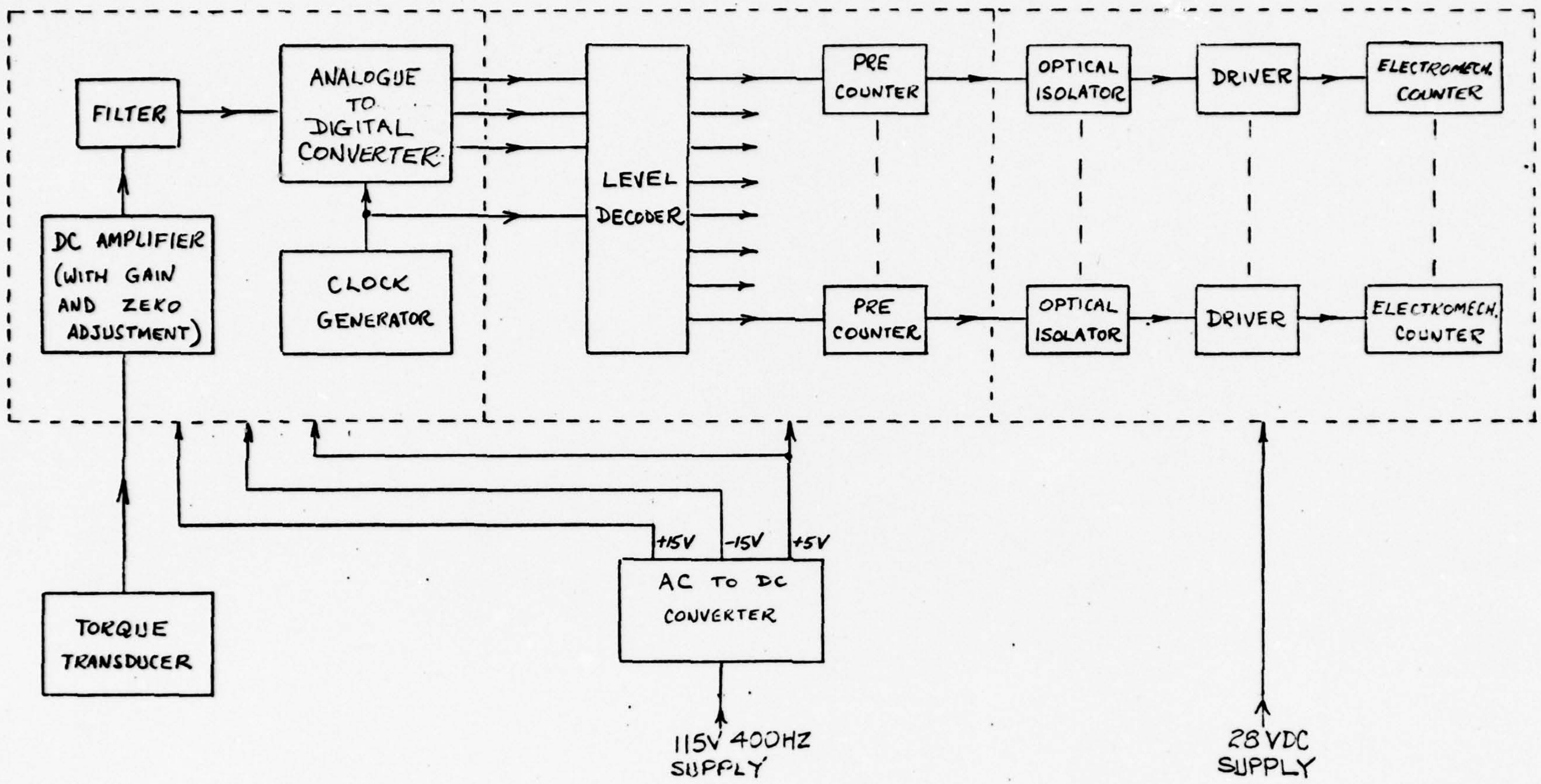
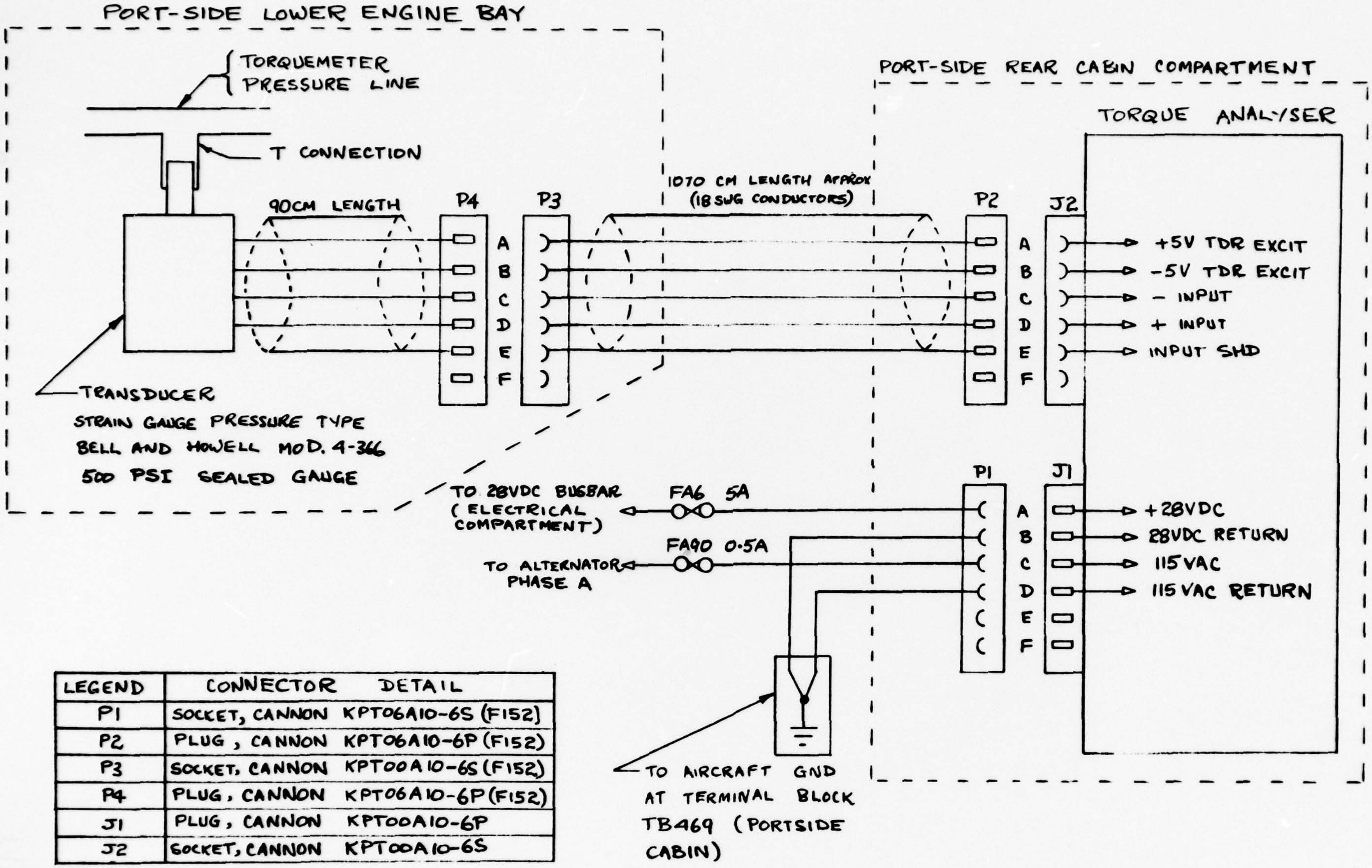


FIG. 1 BLOCK SCHEMA OF TORQUE LOAD SPECTRUM MEASURING EQUIPMENT



LEGEND	CONNECTOR DETAIL
P1	SOCKET, CANNON KPT06A10-6S (F152)
P2	PLUG, CANNON KPT06A10-6P (F152)
P3	SOCKET, CANNON KPT00A10-6S (F152)
P4	PLUG, CANNON KPT06A10-6P (F152)
J1	PLUG, CANNON KPT00A10-6P
J2	SOCKET, CANNON KPT00A10-6S

FIG. 2 CONNECTIONS TO TORQUE MEASURING EQUIPMENT INSTALLED IN WESSEX AIRCRAFT

FIG. 3 TRANSDUCER

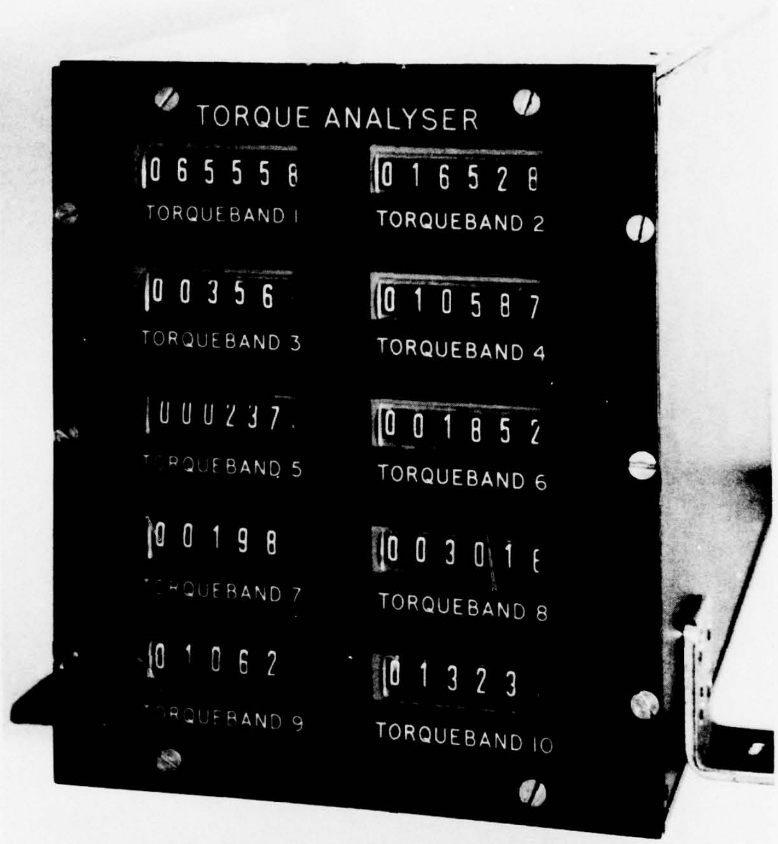


FIG. 4 FRONT VIEW OF TORQUE ANALYSER SHOWING READOUTS

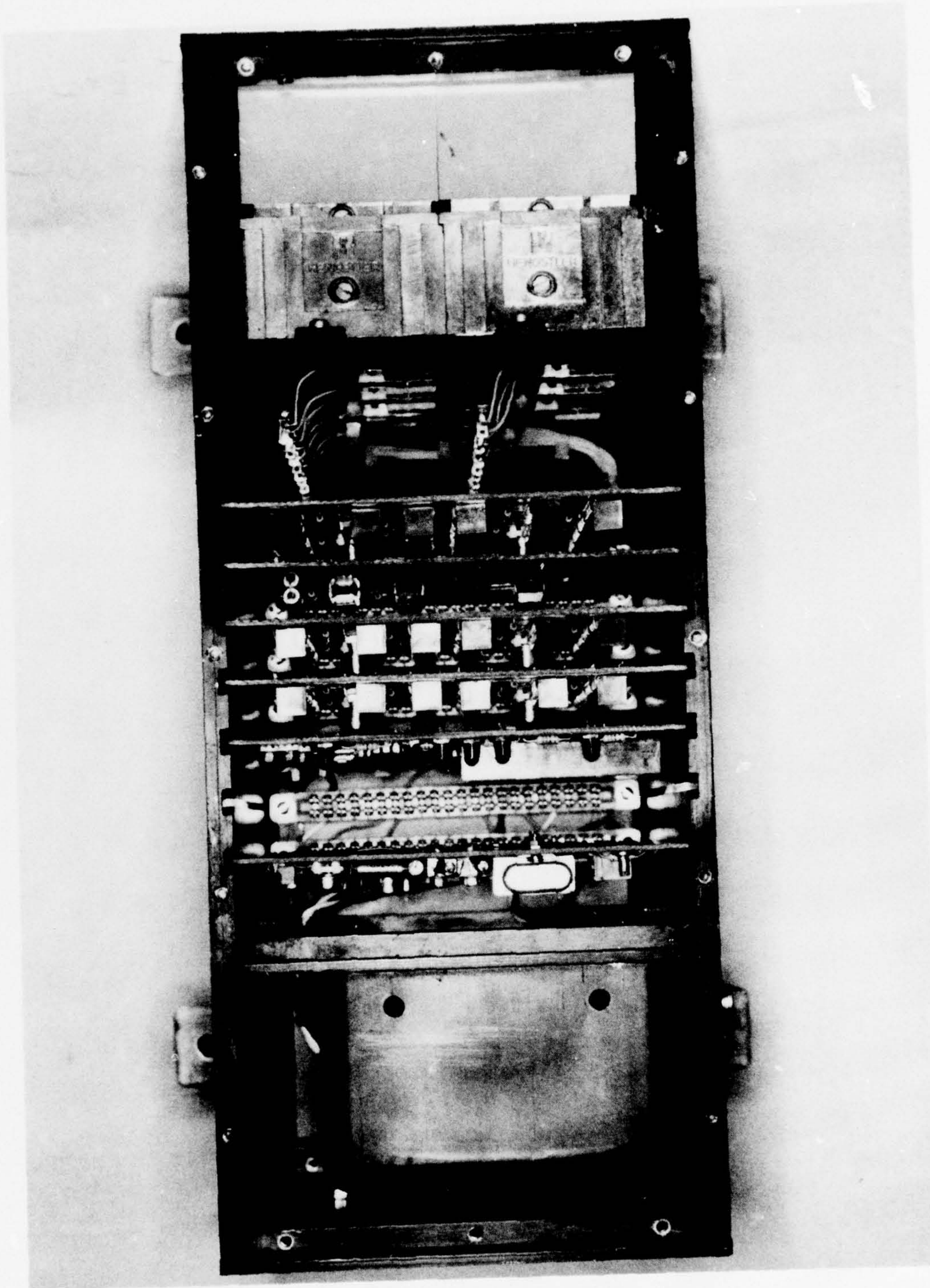


FIG. 5 INTERNAL VIEW OF ANALYSER AS SEEN FROM THE TOP OF THE UNIT.

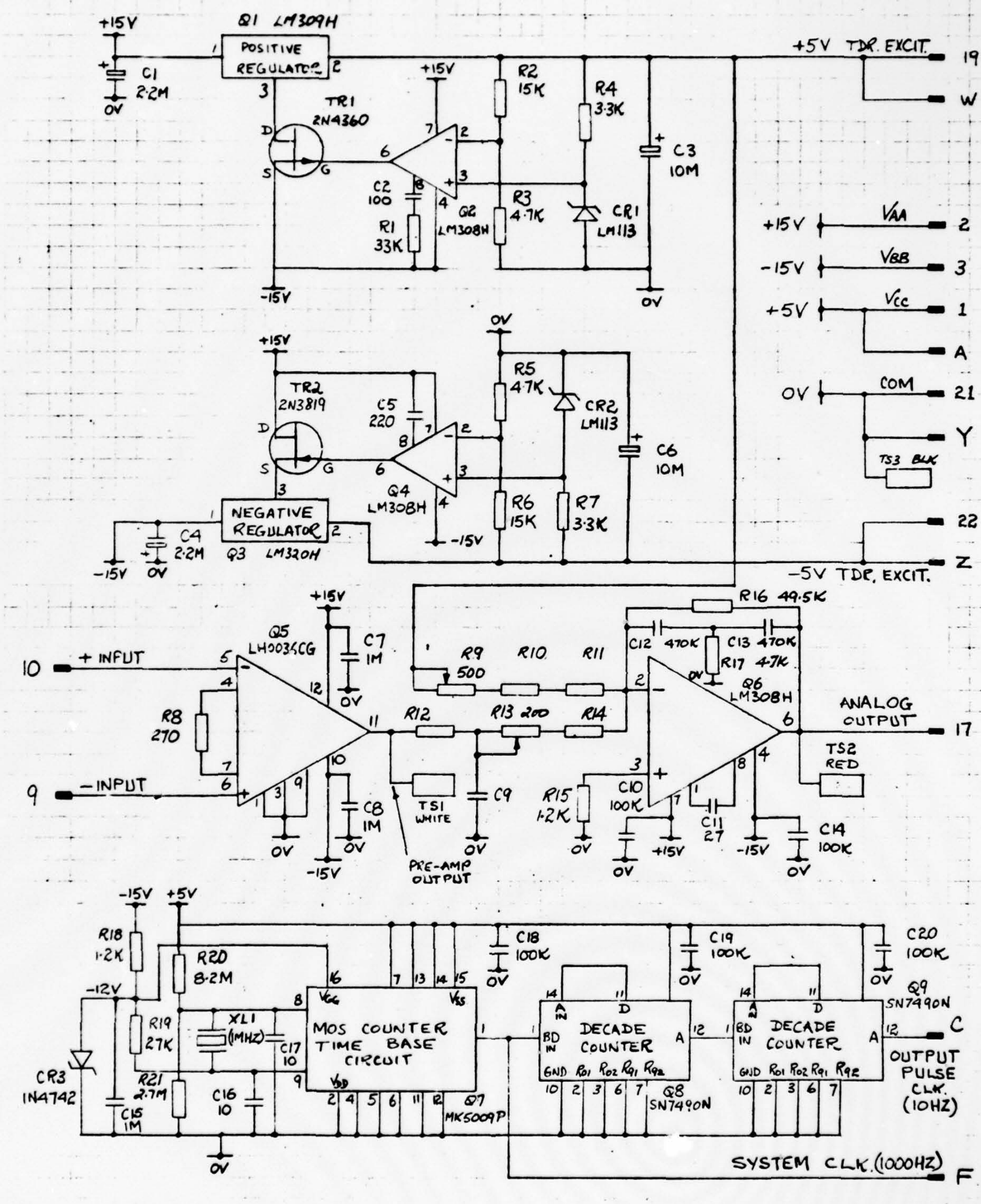


FIG. 6 CLOCK AND PRE-AMP

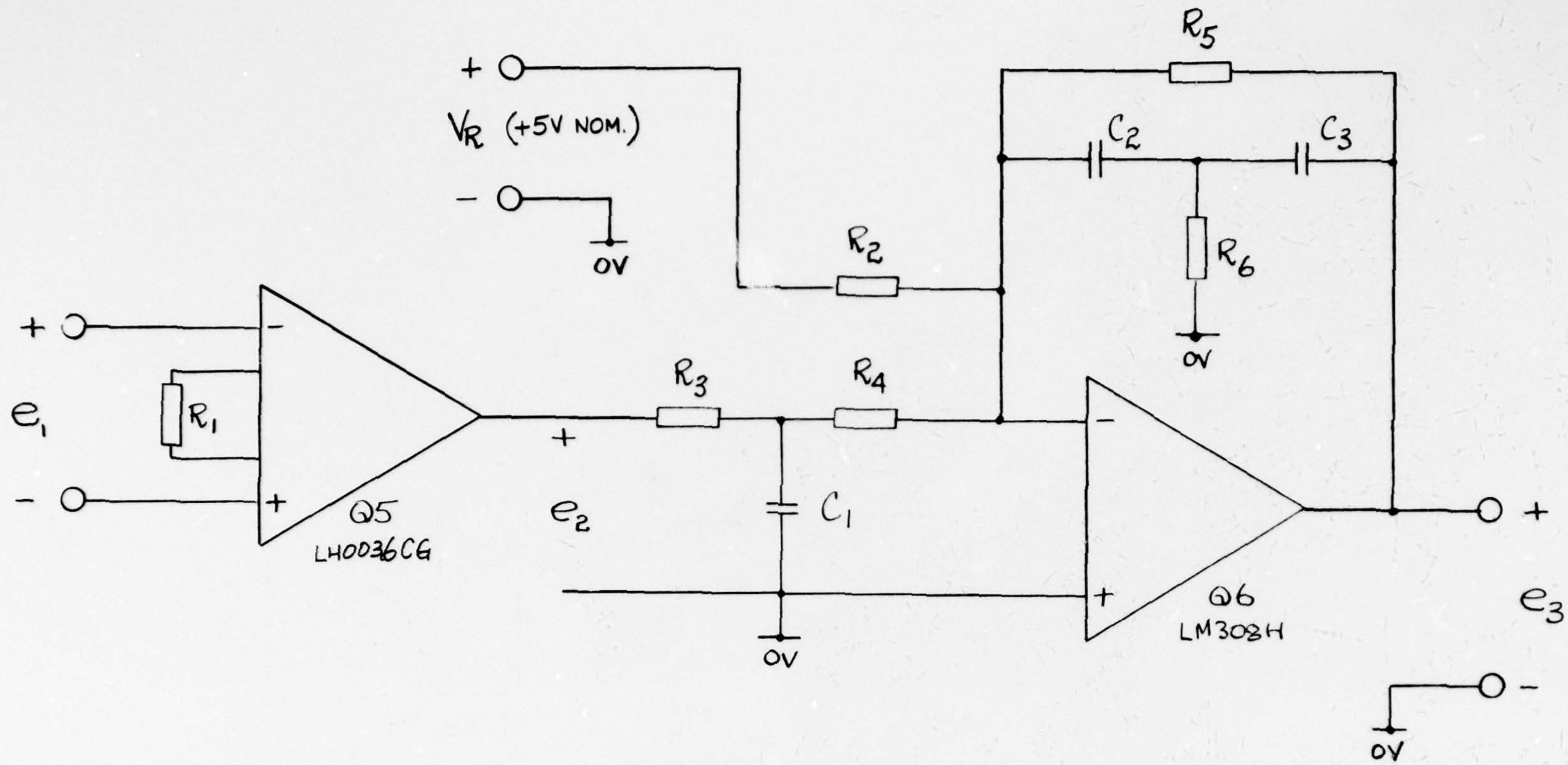


FIG. 7 SIMPLIFIED CIRCUIT OF DC AMPLIFIER AND FILTER

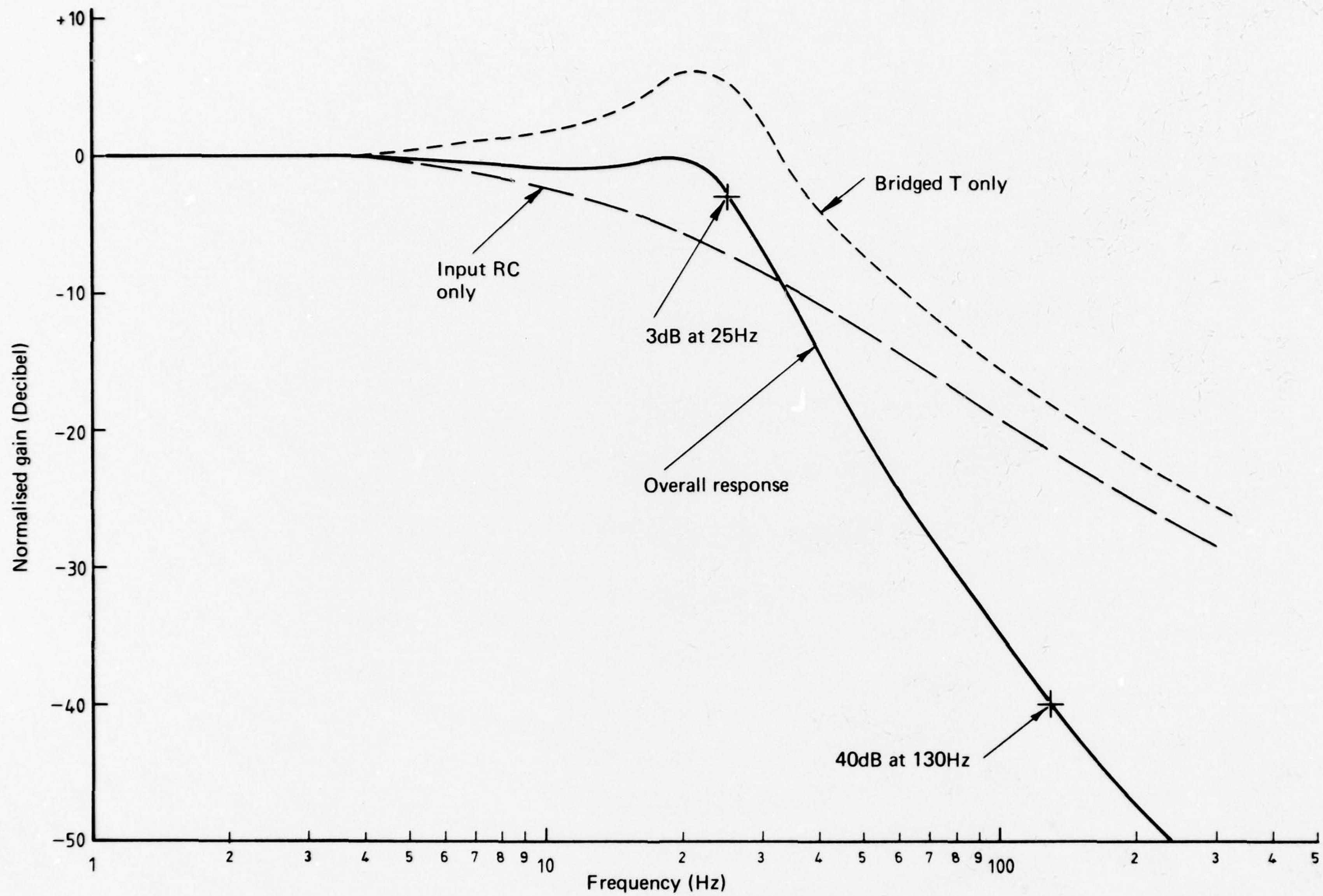
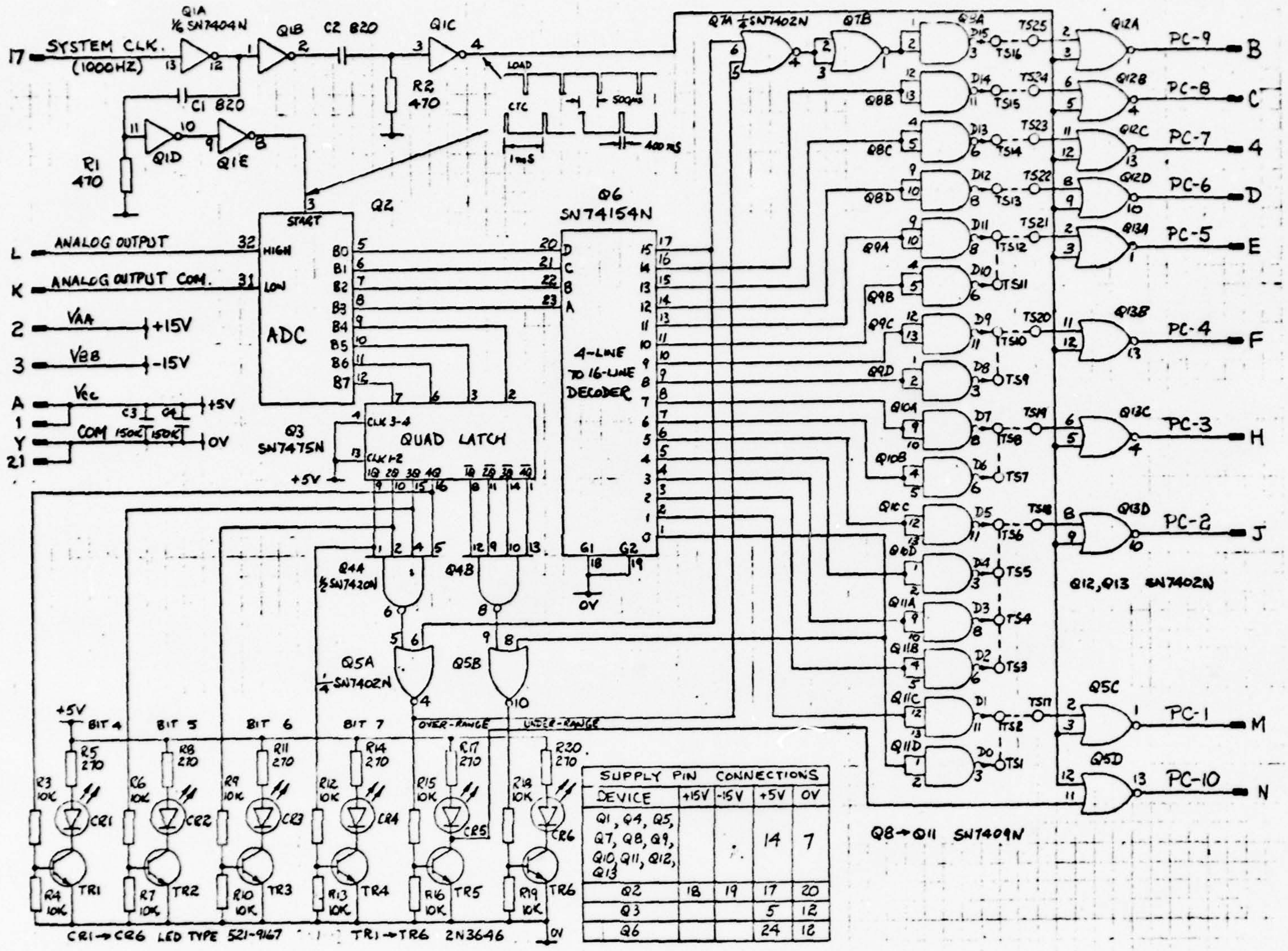
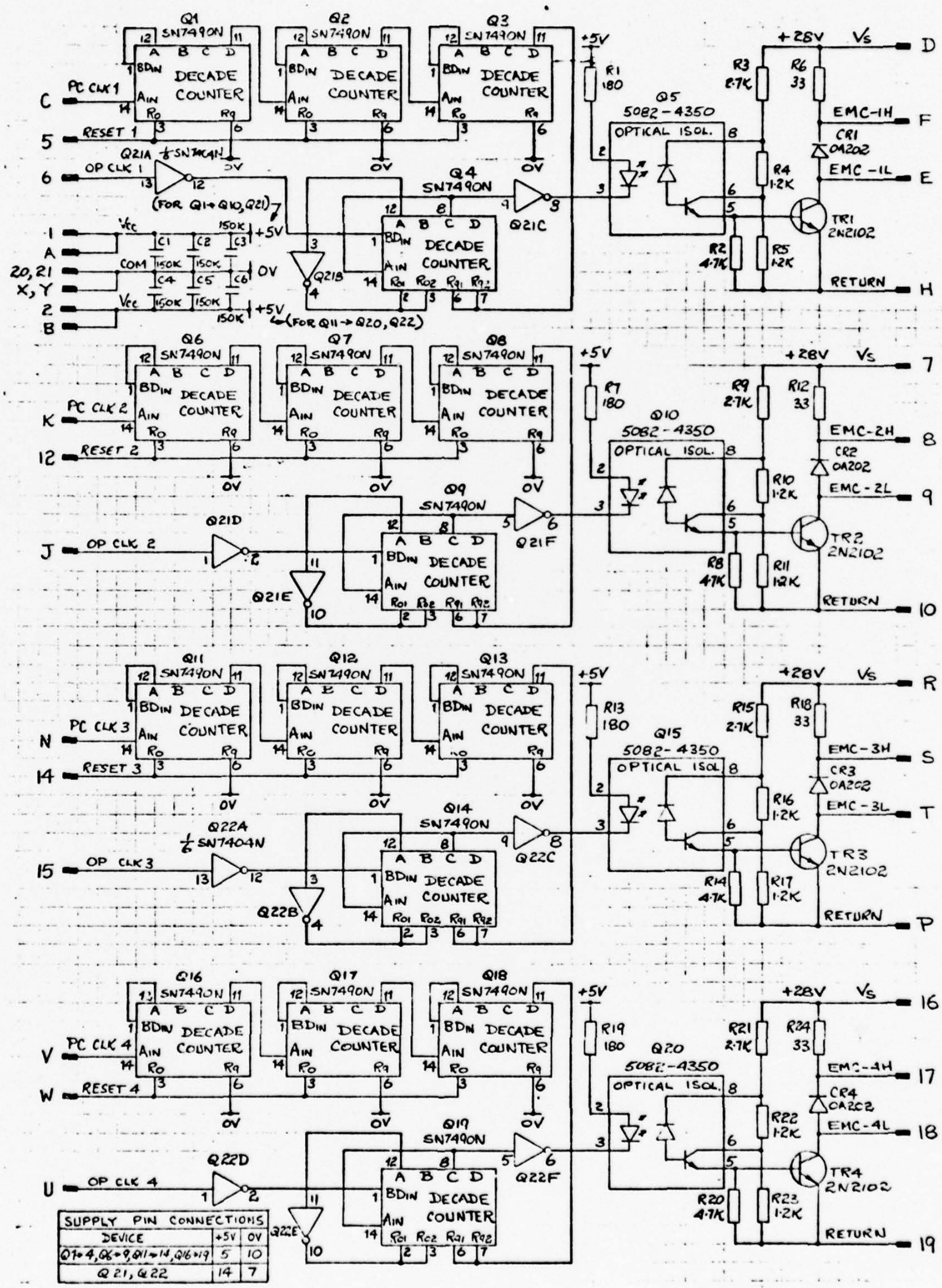


FIG. 8 FILTER RESPONSE CURVES.



SUPPLY PIN CONNECTIONS				
DEVICE	+15V	-15V	+5V	0V
Q1, Q4, Q5, Q7, Q8, Q9, Q10, Q11, Q12, Q13			14	7
Q2	18	19	17	20
Q3			5	12
Q6			24	12

FIG. 9 TORQUE BAND SEPARATOR



SUPPLY PIN CONNECTIONS

DEVICE	+5V	0V
Q1→4, Q6→9, Q11→14, Q16→19	5	10
Q21, Q22	14	7

FIG. 10 QUAD PRE-COUNTER

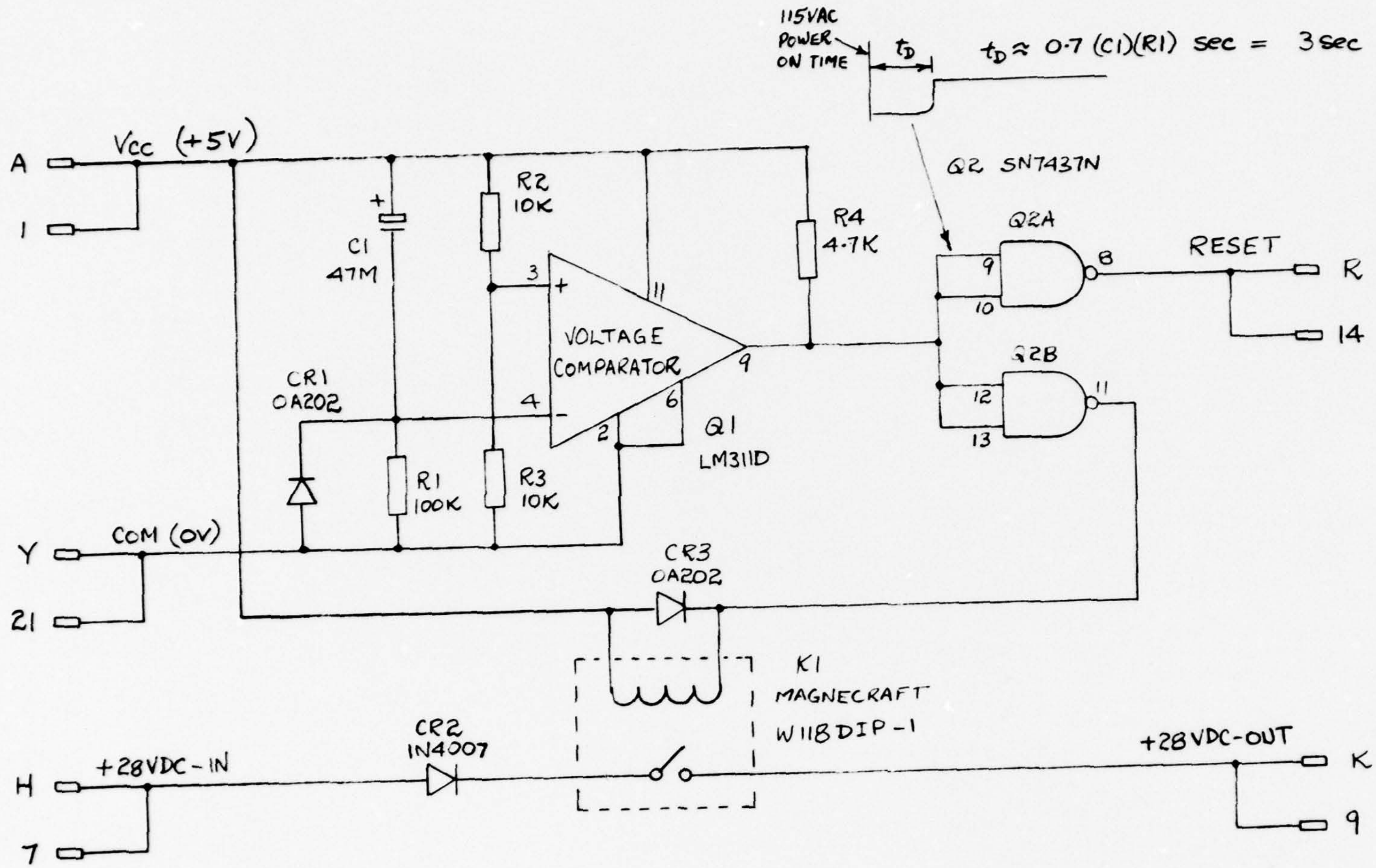


FIG. 11 SWITCH-ON DELAY CIRCUIT

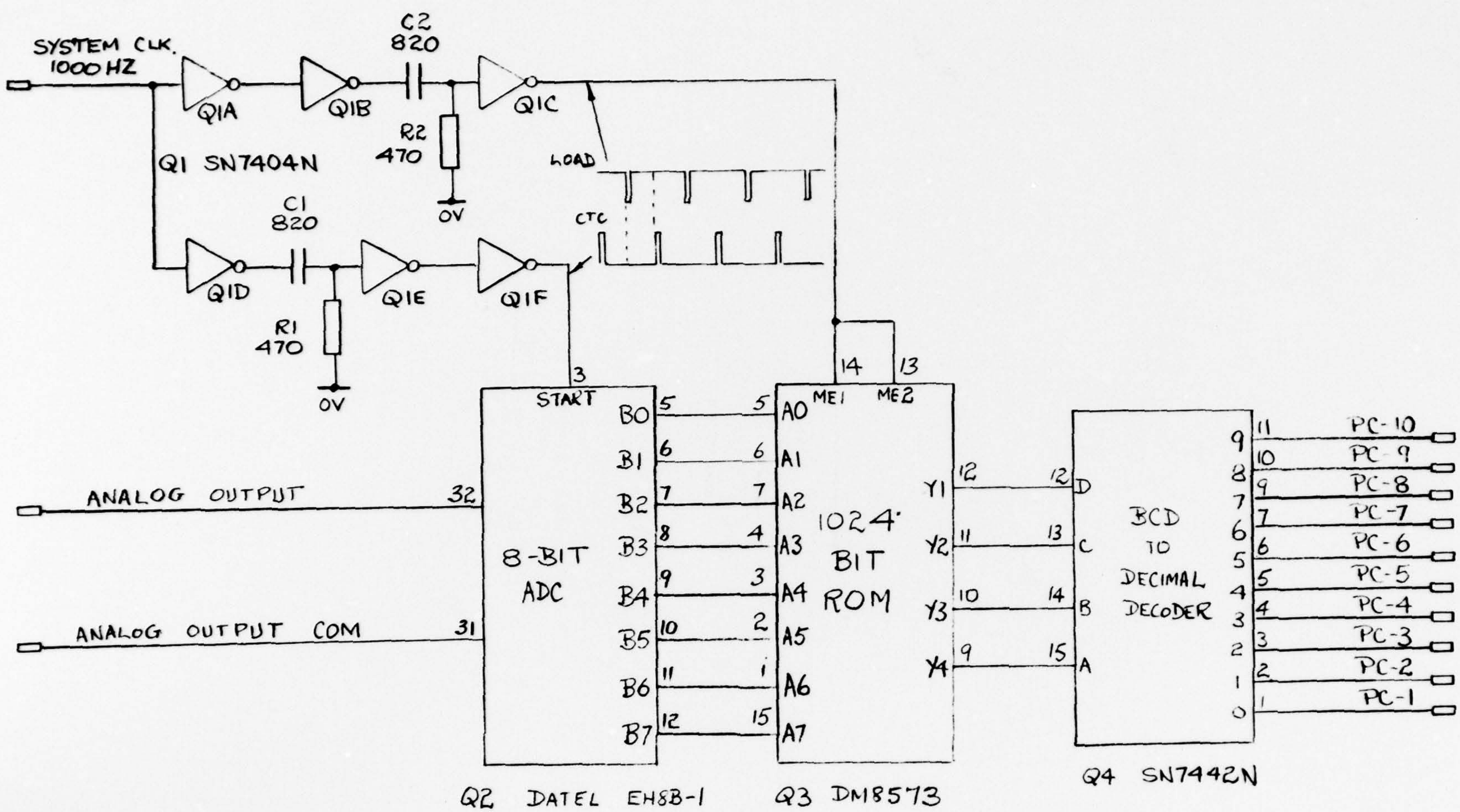


FIG. 12 REPLACEMENT BAND SEPARATOR CIRCUIT

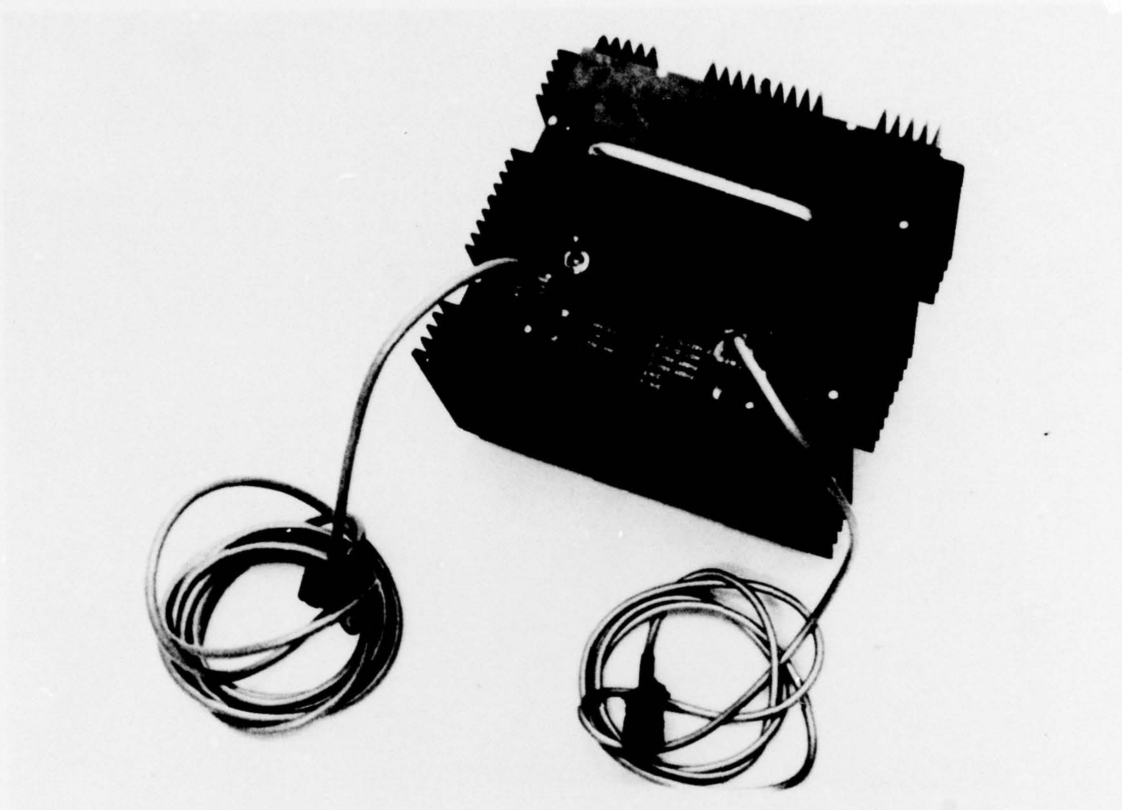


FIG. 13 STATIC INVERTER POWER SUPPLY

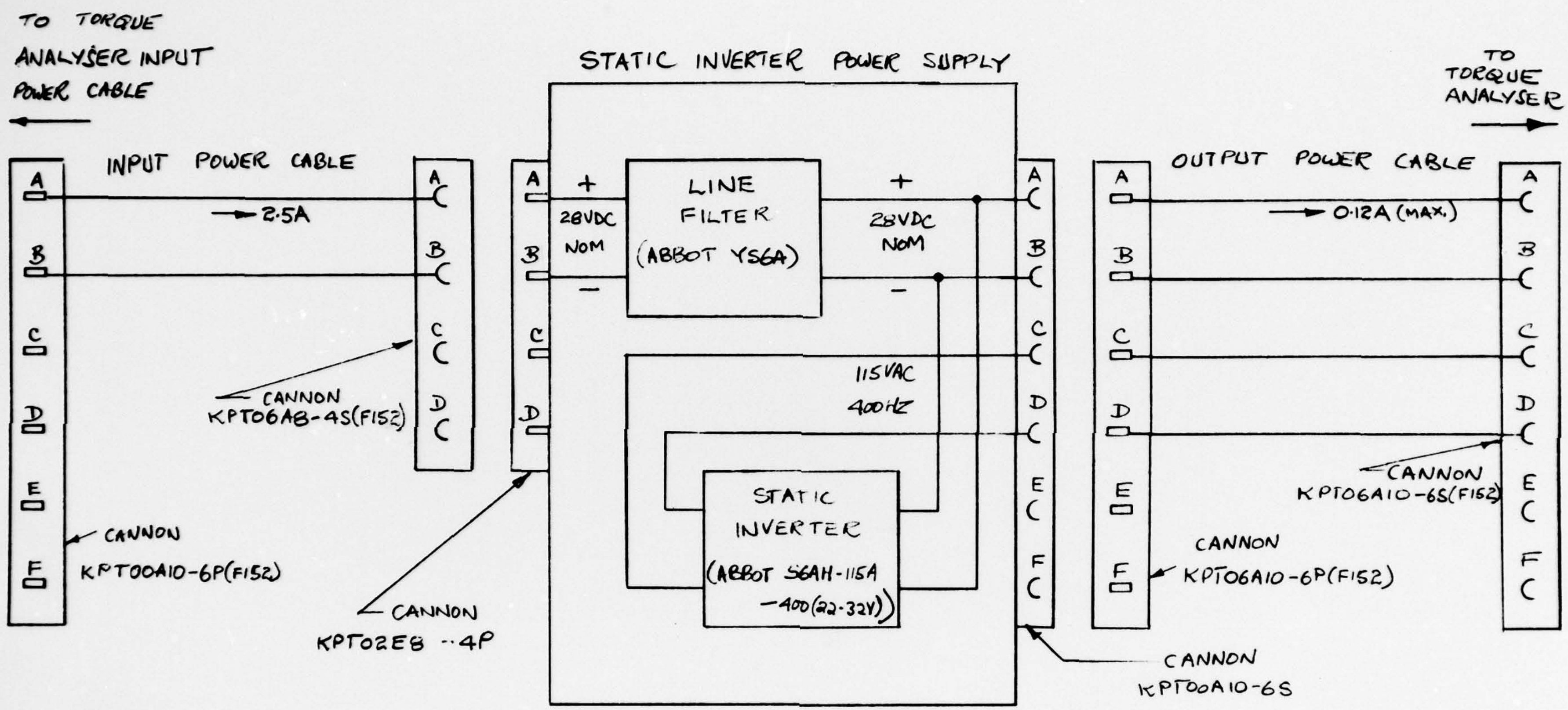


FIG. 14 STATIC INVERTER POWER SUPPLY CONNECTION DETAILS

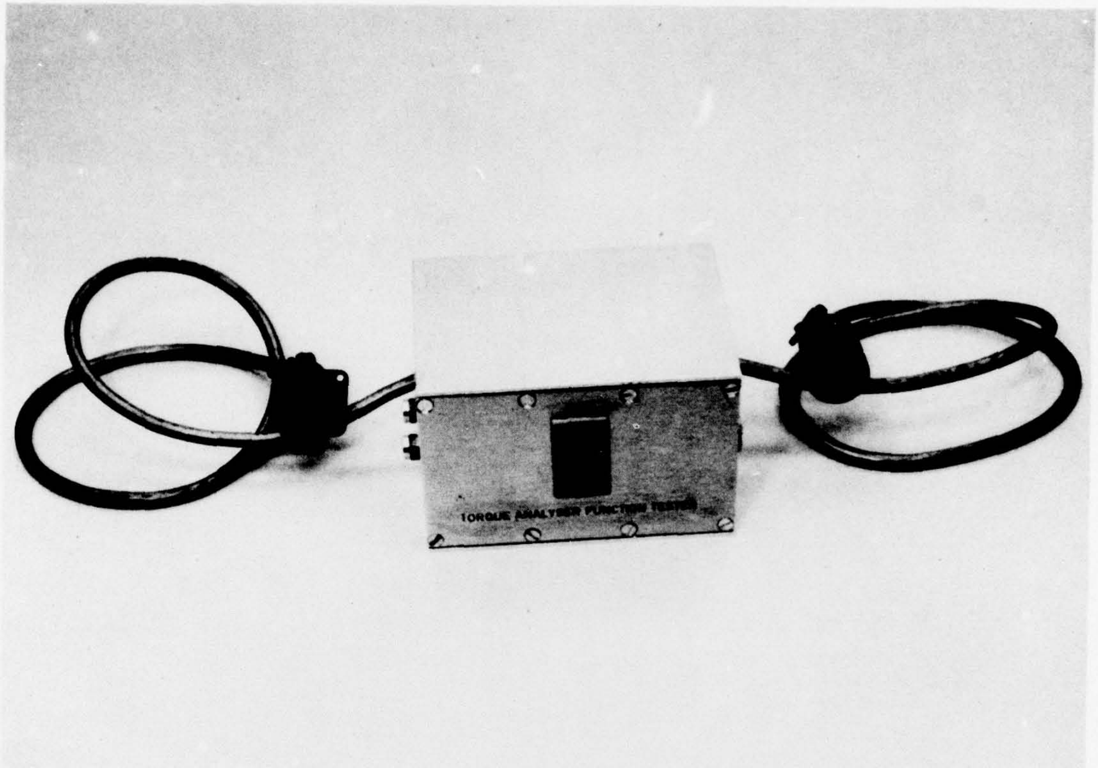


FIG. 15 TORQUE ANALYSER FUNCTION TESTER

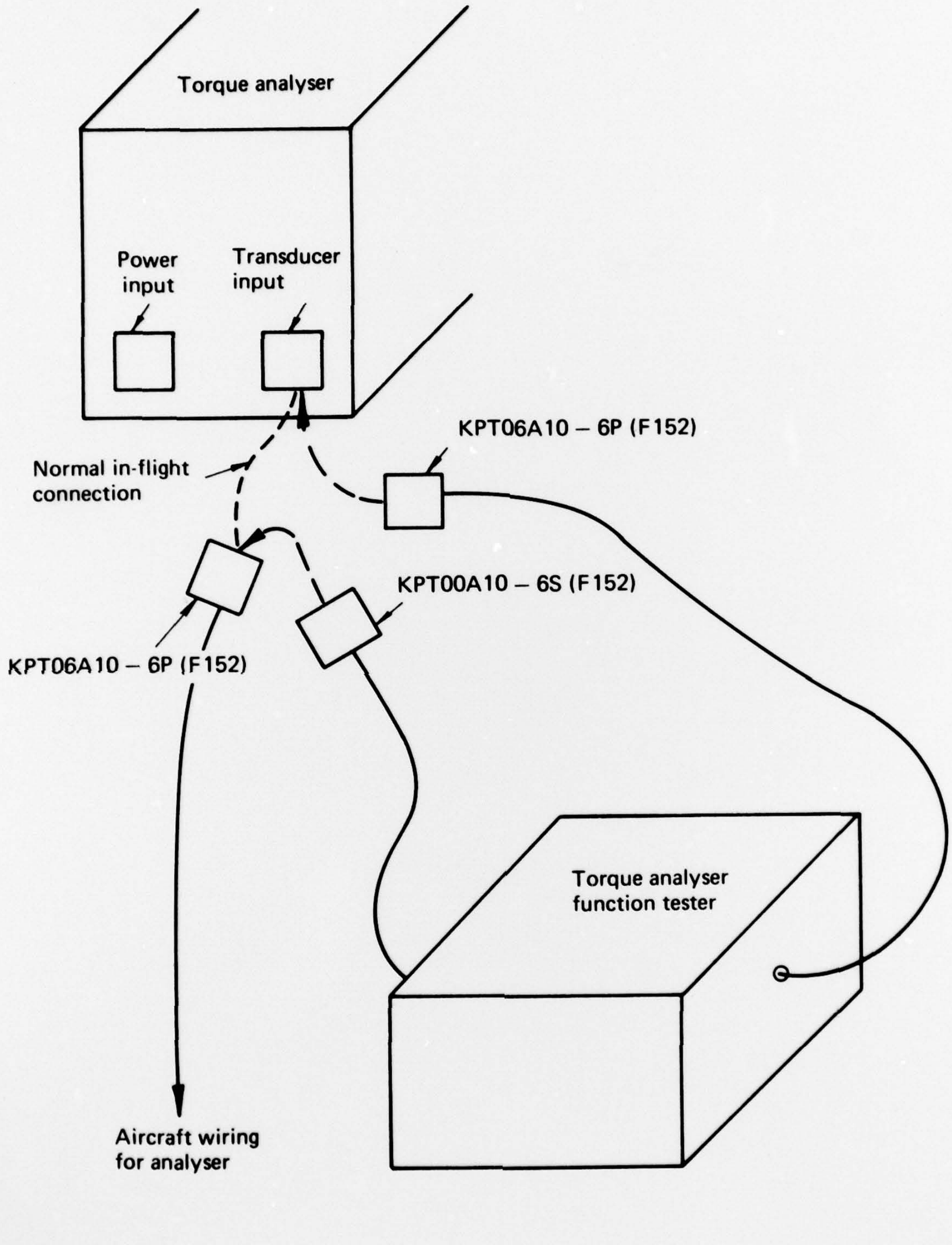


FIG. 16 CONNECTION OF FUNCTION TESTER TO TORQUE ANALYSER

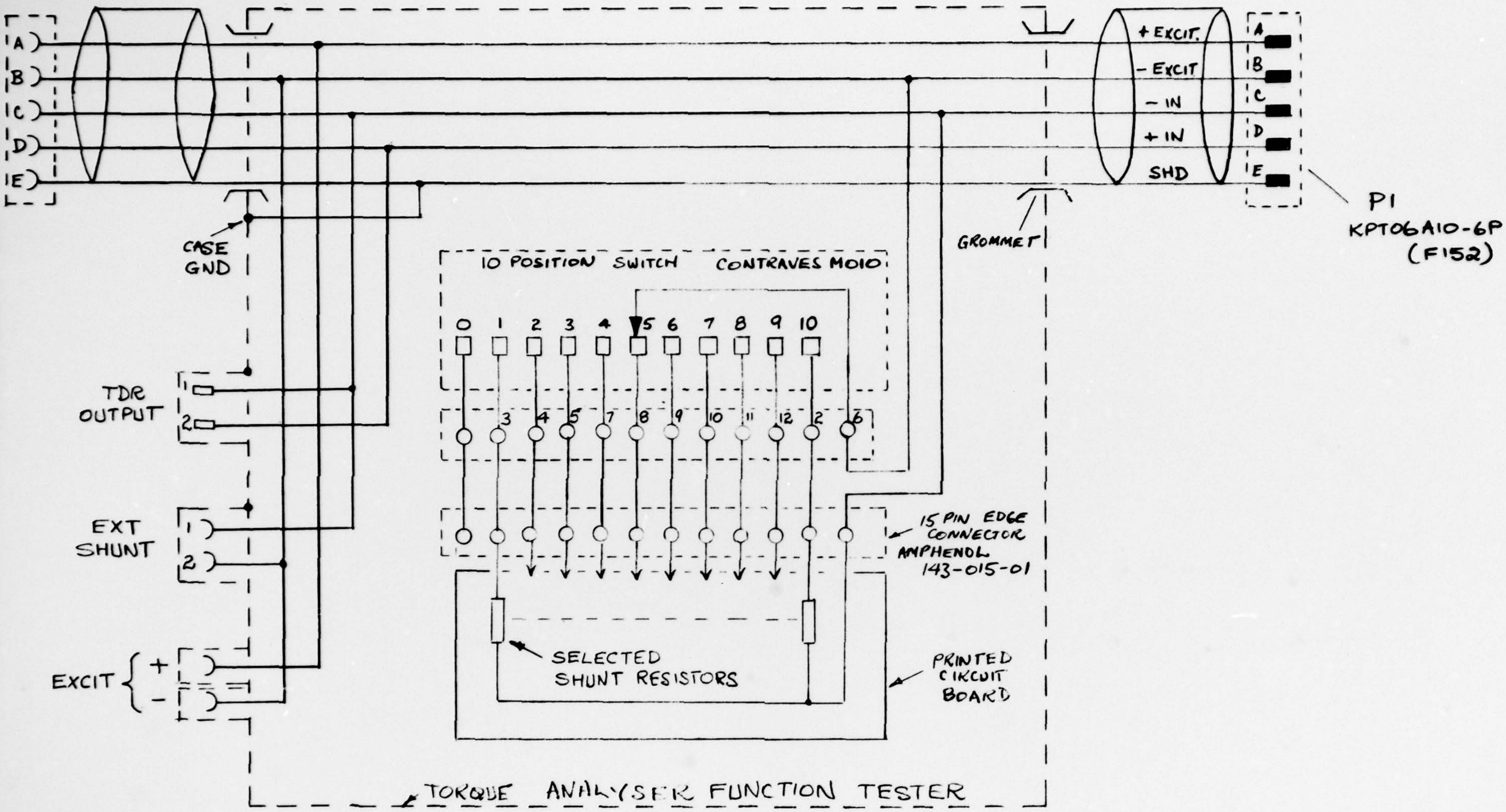


FIG. 17 CIRCUIT DETAILS FOR TORQUE ANALYSER FUNCTION TESTER

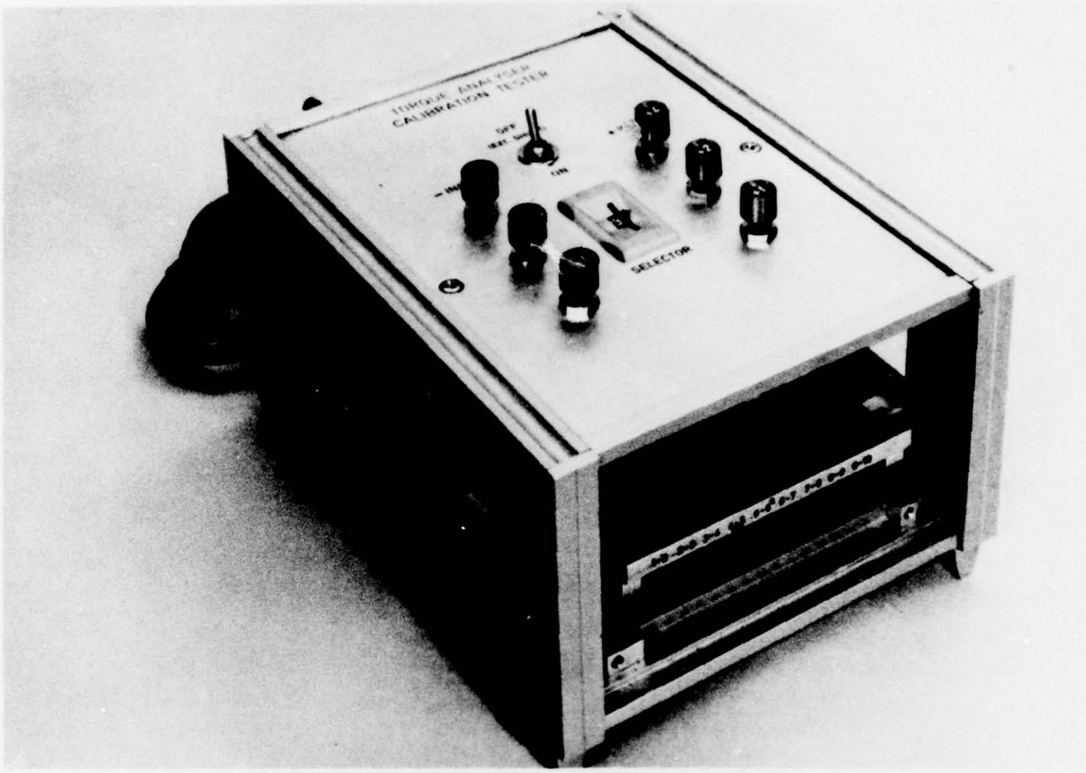


FIG. 18 TORQUE ANALYSER CALIBRATION TESTER
(With side covers removed)

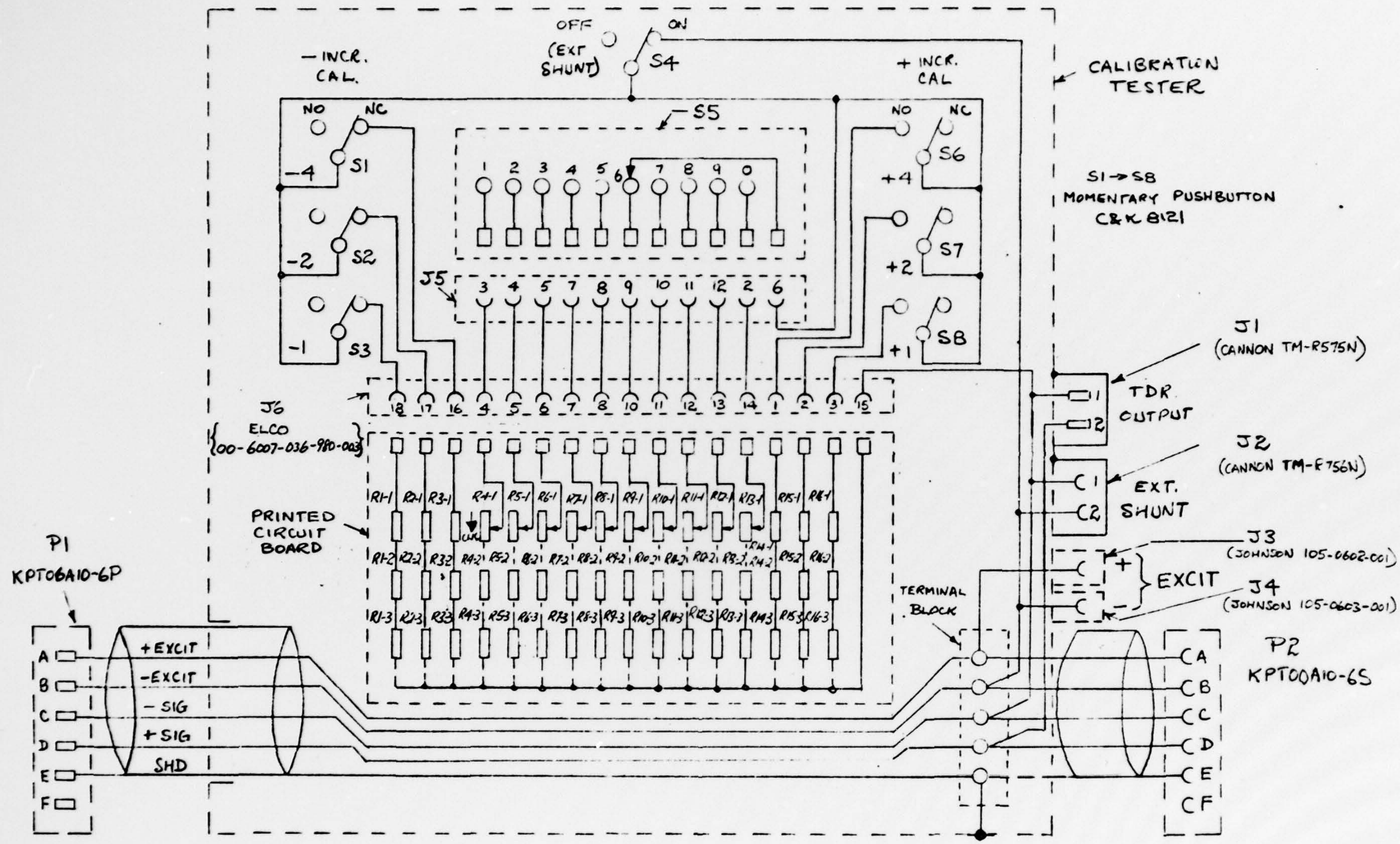
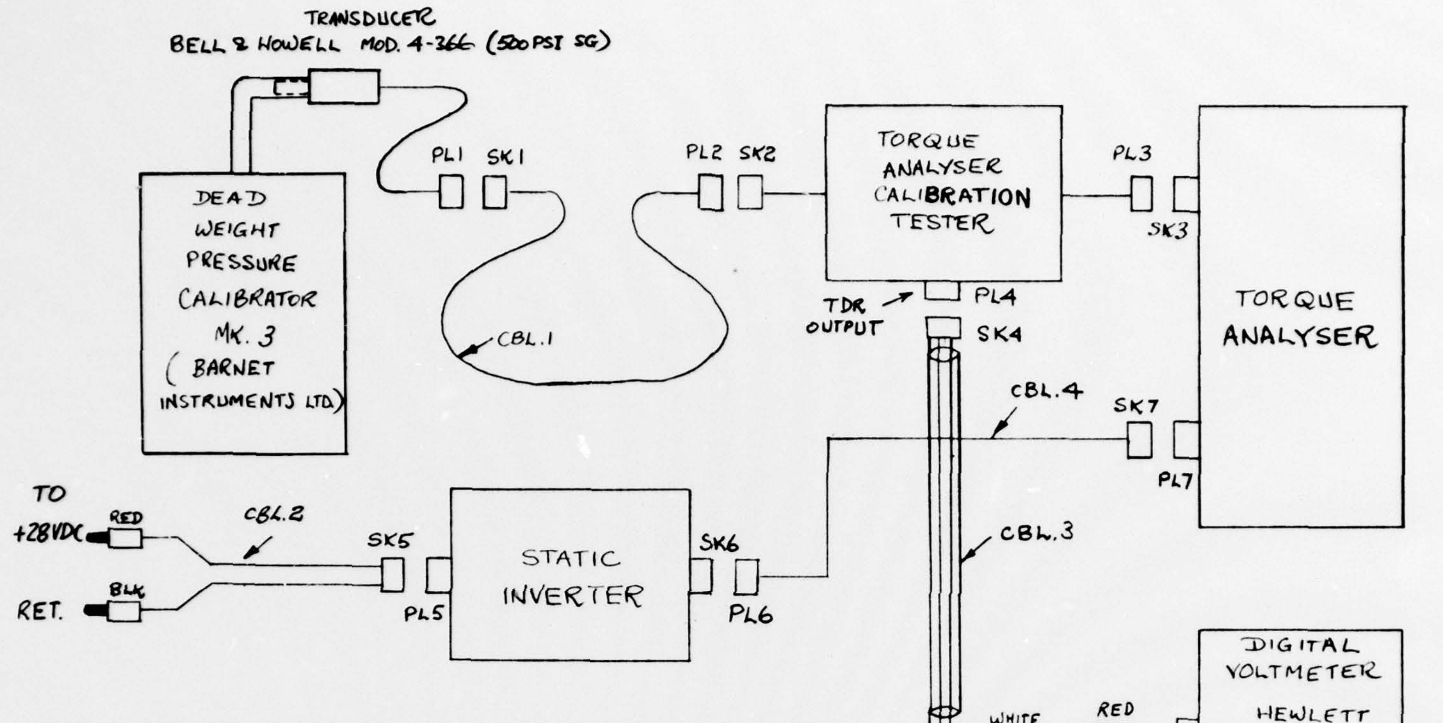


FIG. 19 CIRCUIT DETAILS FOR TORQUE ANALYSER CALIBRATION TESTER



CONNECTOR DETAILS			
LEGEND	DESCRIPTION	LEGEND	DESCRIPTION
PL1	6pin, Cannon KPT06A10-6P(F152)	SK1	6pin, Cannon KPT00A10-6S(F152)
PL2	As for PL1	SK2	As for SK1
PL3	As for PL1	SK3	As for SK1
PL4	2pin, Cannon TM-R575N	SK4	2pin, Cannon TM-R539N-11
PL5	4pin, Cannon KPT00A8-4P	SK5	4pin, Cannon KPT06A8-4S(F152)
PL6	As for PL1	SK6	As for SK1
PL7	6pin, Cannon KPT00A10-6P	SK7	6pin, Cannon KPT06A10-6S(F152)

FIG. 20 CONNECTION OF EQUIPMENT FOR CALIBRATION WITH DEAD WEIGHT TESTER

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Torque	Electromechanical transducers
Automotive transmissions	Analog to digital converters

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    2011

16. *ABSTRACT*

Measuring equipment has been developed which uses a set of electromechanical counters to indicate the integrated time in seconds for which torque loading on a transmission component falls within each of a number of bands.

Separation of the torque level into bands is made possible using a single transducer, an amplifier with zero and gain adjustments for setting the extremes of the torque range of interest, an analogue to digital converter and decoder to separate the torque range into bands and counters to totalize contributions in each band.

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